Wingship Investigation

VOLUME 2

Appendices

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Coordinated and
Published for

Advanced Research Projects Agency
3701 N. Fairfax Drive
Arlington, VA 22203-1714

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	9/30/94	Final Report

4. TITLE AND SUBTITLE
Wingship Investigation - Volume 2 - Appendices

5. FUNDING NUMBERS

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Advanced Research Projects Agency (ARPA)
3701 N. Fairfax Drive
Arlington, Virginia 22203-1714

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Advanced Research Projects Agency (ARPA)
3701 N. Fairfax Drive
Arlington, Virginia 22203-1714

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
N/A

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Distribution is Unlimited

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION IS UNLIMITED (A)

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Advanced Research Projects Agency (ARPA) has completed an investigation of Wingship concepts and technologies to examine their relevance and utility in future defense applications. A select team of technical experts from U.S. Government and industry was formed by ARPA to assess Wingship-related technologies and mission applications. The diverse group was comprised of Western experts in Wingship-unique and related technologies, including flight controls, aerodynamics, hydrodynamics, propulsion, and advanced structures. Transportation specialists and other mission analysts also participated. The Wingship Investigation concluded that vehicles approaching the efficiency and capacity required for strategic heavy lift are about 10 times larger (in gross weight) than any existing Wingship or other flying water-based craft, and about five-times larger than most experienced Russian or American experts recommend building using current technology. The study concluded that, while the cost and technical risks of developing these very large Wingships are currently unacceptable, there may be some promising military applications for Wingships in the 400- to 1000-ton range. Experience with these relatively smaller vehicles could also permit a growth path for the technology.

14. SUBJECT TERMS
Aerodynamic ground effect, Wingship,
Ekranoplan (Russian)

15. NUMBER OF PAGES
668

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
	UNCLASSIFIED	UNCLASSIFIED	

Wingship Investigation

Appendix

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Wingship Investigation

Congressional Language and Official Correspondence

Appendix A

Congressional Direction

The conferees direct that, from within the total amount of funds appropriated for this program element, **$5,000,000 is available only for the Wingship project** and $5,000,000 is available only for the advanced sonar automation system project. The conferees direct that in providing funds for these projects, the Defense Advanced Research Projects Agency shall not decrement any other activities to which Congress has added funds or which have been designated as items of special Congressional interest.

The funds to be made available for the Wingship project may **only be used for experimental planning** and **may not be used to enter into any contractual arrangement which would commit the government to proceed beyond the planning stage.** No later than **May 1, 1993**, the **Secretary of Defense** is directed to **report to the Congressional defense committees** whether there is a **validated military requirement for a wingship** and how any need for such a system relates to other programs to improve U.S. airlift and sealift capabilities. This report also should contain a clear statement of policy whether the Defense Department would want to pursue a wingship program.

ADVANCED RESEARCH PROJECTS AGENCY
3701 NORTH FAIRFAX DRIVE
ARLINGTON, VA 22203-1714

MAY 3 1993

Professor Andrey Kokoshin
First Deputy Minister of Defense
Ministry of Defense
Russian Federation of States
Moscow, Russia

Dear Professor Kokoshin:

In accordance with direction provided by the United States Congress, the Advanced Research Projects Agency is undertaking a study to evaluate wing-in-ground effect vehicle technology to help us assess whether the United States should employ such systems in our defense infrastructure. Termed "The Wingship Study," this effort will focus on understanding the state of the art in development of these vehicles and their operational potential. In addition, given recent concerns over the conversion of our defense industry in this country, there is significant interest in understanding potential commercial applications.

We are aware of the "Ekranoplan" and other wingship development which has taken place in Russia and the other nations of the former Soviet Union. We fully appreciate the investment which you have made in developing this advanced technology. An assessment of the type we propose would be incomplete without an understanding of the advances you have made in this area.

I have formed a small, but expert technology evaluation team to undertake this project. This group is led by LtCol Michael S. Francis of my office and has a charter to provide an assessment of worldwide developments in this area and to assess prospects for developing and employing this technology in applications in this country. LtCol Francis' task will be to gather as much information as possible on the development and operational issues associated with these systems and their constituent components to support a decision on future investment and/or development. If our assessment is to be successful, the initial phase of this study should involve discussions with your development and operational communities. A potential outcome of a favorable early result would be a plan for experiments to further evaluate the types of wing-in-ground effect vehicles which you have developed.

The members of this technology team, both government and industry, were selected because of their special expertise and capabilities to evaluate the Wingship technologies. Many of them have extensive research experience in wing-in-ground effect type vehicles, while others have similar depth of expertise in other areas highly beneficial to this study. In our interface with

5

Russian industry, it is our intent to provide fair compensation for technical and engineering support and provide requisite protection for proprietary data.

I view the Wingship study as a unique opportunity to build another productive bridge in the relationship between our two countries and also as a potential area for economic interchange in the future. I look forward to working with you and the people of the Russian Federation as we progress through this Wingship Technology Investigation.

Sincerely,

Gary L. Denman
Director

ADVANCED RESEARCH PROJECTS AGENCY
3701 NORTH FAIRFAX DRIVE
ARLINGTON, VA 22203-1714

May 7, 1993

LCDR Jeff Kypers, Defense Attache
American Embassy
Noviskii Bulvar - 19/23
Moscow, 121099
Russia

Dear LCDR Kypers,

The purposes of this letter are to (1) transmit the enclosed communication of 3 May 1993 from the Director of the Advanced Research Projects Agency, Gary L. Denman, to Prof. Andrey Kokoshin, First Deputy Minister of Defense in Russia and, (2) to advise regarding an official United States government sponsored visit to Russia by four U.S. citizens on the topic of the enclosure.

The enclosure identifies that a trip by the United States to Russia is desired on the topic of wingships. You may also wish to refer to country clearance request "P 231540Z APR 93 PSN 857664M36" sent previously to USDAO Moscow RS//AIRA//.

The visit is currently planned to be made by the four individuals named in the country clearance request - Dr. John Thomas, Edmond D. Pope, CAPT/USN, Michael S. Francis, LtCol/USAF and Dr. Roger W. Gallington. Captain Pope will be leaving the U.S. on 5/22 for other business in Russia on 5/24-25 and will join the other three in Moscow for their meetings with the Russians on the wingship topic. Dr. Thomas, LtCol Francis and Dr. Gallington will be leaving the U.S. on Saturday 29 May 1993 and will depart no later than Saturday 5 June 1993.

Sincerely,

MICHAEL S. FRANCIS, LtCol USAF
Program Manager (ARPA/ASTO)

Enclosure

Science Applications International Corporation
An Employee-Owned Company

May 14, 1993

Mr. Shykind

Dear Mr. Shykind,

Here is the information on the ARPA Wingship Study you requested. I received your request from Lt.Col. Mike Francis at ARPA. We have not yet prepared a compact study description to hand out. But, since Mike has asked me to send packages to three people this week, we will probably develop a more polished package soon.

In the meantime, I have enclosed:

(1) The initial study kickoff briefing.
(2) The Program Approval Document (an internal ARPA management document)
(3) Letters to the American Embassy in Russia and the Russian First Deputy Minister of Defense concerning our first planning trip.
(4) A recent study program schedule
(5) A very early draft of the final report outline.

This is a study/evaluation effort only and not a development program. Notice especially that Congress directed that ARPA do this study and that the study focuses on DoD requirements.

We have lots of additional information including a constantly-expanding database containing the factual information which will eventually support the conclusions, short biographies of all participants, and meeting minutes etc. I will be pleased to supply any other information you request.

Sincerely yours,

Roger W. Gallington

Roger W. Gallington, Ph.D.
Assistant Vice-President

attachments

FAX (202) 482-2834

SAIC

Science Applications International Corporation
An Employee-Owned Company

May 14, 1993

Vince Rauch
NASA
Code RN
Washington, DC 10546

Dear Mr. Rauch

Mike Francis asked me to send you some information on the ARPA Wingship evaluation. We haven't yet developed a polished description intended to be distributed outside the study. Therefore I have selected from our existing documents some that will hopefully be informative.

Specifically, I have included:

(1) The initial study kickoff briefing.
(2) The Program Approval Document (an internal ARPA management document)
(3) Letters to the American Embassy in Russia and the Russian First Deputy Minister of Defense concerning our first planning trip.
(4) A recent study program schedule
(5) A very early draft of the final report outline.
(6) Sole source justification for RAS.

You may request any additional information directly from me.

Sincerely,

Roger W. Gallington

Roger W. Gallington, Ph.D.
Assistant Vice-President

attachments

FAX (202) 358-3640

ADVANCED RESEARCH PROJECTS AGENCY
3701 NORTH FAIRFAX DRIVE
ARLINGTON, VA 22203-1714

September 1, 1993

To: Vice Admiral Venomin Polyanski
Director Navy Shipbuilding
Navy of the Russian Federation
Moscow, Russia

Subject: Wingship Team Visit to Caspian,
Orlyanuk Flight Demonstration

The ARPA Wingship Technical Evaluation Team (WTET) is nearing completion of its evaluation. The group is experiencing problems arriving at significant conclusions because of the lack of available flight test data to support performance assertions or to resolve inconsistencies in verbal data provided to the group in its discussion with the Russian technical community. The lack of answers to several key performance-related questions have precluded a meaningful extension of results to predict the performance and value of future designs (both American and Russian) currently being considered.

The WTET visit to witness the Orlyanuk demonstration in late September affords a final opportunity to resolve these fundamental issues. To this end, I request the information outlined in attachment 1 be provided. To allow the WTET to prepare for the trip to the Caspian in September, it is essential that the historical information detailed in paragraph 1 of the attachment be provided to the WTET no later than 20 September 1993.

Futhermore, my expectation is that we will be permitted to photograph and video tape the vehicle used in the flight demonstrations (interior and exterior) at the test sight and during the demonstrations.

Inasmuch as we have asked these specific questions previously, and given the significance and magnitude of our investment in this short term demonstration activity, I believe that these requests are both reasonable and justified. Let me emphasize, the future of the WINGSHIP project, in general, as well as a potential

cooperative project, hinges on a meaningful set of conclusions and a positive recommendation by the study team.

Your support and cooperation would be greatly appreciated.

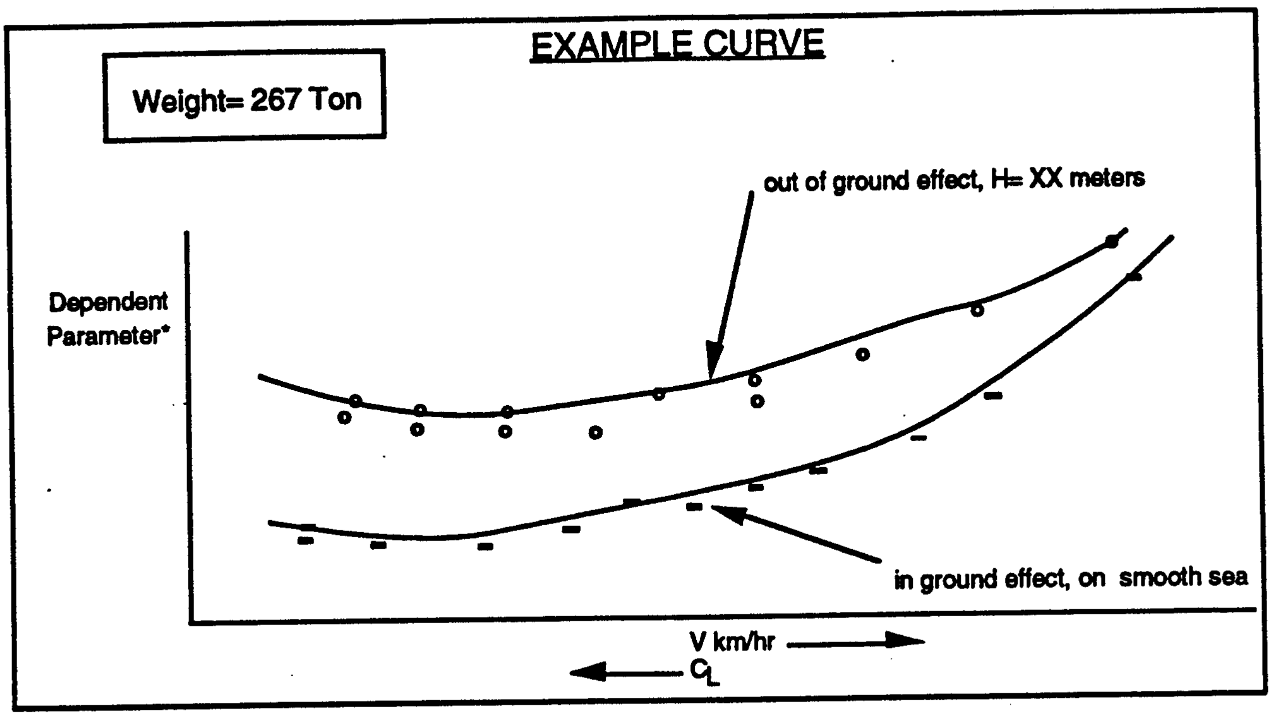
Sincerely,

Michael S. Francis LtCol, USAF
Program Manager
ARPA/ASTO

REQUEST FOR SPECIFIC DATA TO JUSTIFY THE LATE SEPTEMBER EXERCISE

1) Historical Performance Flight test Data for large wingships: KM (Caspian Sea Monster), ORLAN, LUN. Actual original flight test data reports, including, as a minimum:

A. Raw test data measurements from flights dedicated to the determination of flight efficiency. These should be for several heights and/or sea states, as shown, as a function of speed or lift coefficient (C_L) and at heights representative of low sea skimming and at higher altitudes.



PARAMETERS *- fuel flow, Torque/RPM (Turboprop), fan speed/engine pressure ratio for turbofan, flap position, angle of attack.

CONSTANTS - weight, pressure altitude, outside air temperture.

Time History of takeoff and landing, showing velocity, engine parameters, height, flap position, angle of attack, PAR (thrust line inclination), elevator position, pitch attitude.

B. Correlation of the raw flight test data and calculation of engine thrust and aircraft drag (C_d vs. C_L) for each height flown.

C. Flight reports, or ships' logbook.

2) The September demonstration itself should encompass these flight activities:

In-Ground-Effect (IGE) Flight

Routine Takeoff and Landing

Turning and Maneuvering

Out-of-Ground-Effect (OGE) Performance

3) Demonstration of land-based operations and overland performance.

4) On the actual flights flown in late September, measure data to spot-check the basic performance capability during conventional IGE flight. Record fuel flow, torque & RPM at several airspeeds to include near-minimum speed to maximum allowed speed, at lowest practical height. Repeat at highest practical height. Record aircraft gross weight and detailed definition of configuration (flap position, CG, etc.). Include time history of takeoff and landing. These can be done by hand-held video camera of instrument panel instruments.

5) Demonstration attendees be allowed to interact with Russian flight test personnel, including engineers and pilots, to answer specific questions related to the demonstrations. Descriptions and duties of flight crew during takeoff cruise and landing should be provided.

Science Applications International Corporation
An Employee-Owned Company

September 23, 1993

Mr. Robert Robeson
Vice President of Civil Aviation Division
Aerospace Industries Association
1250 I St. NW Suite 1100
Washington, D.C. 20005-3924

Dear Mr. Robeson

I recently learned that the AIA sponsored a workshop on "Landplane and Seaplane Co-Production" on September 23rd. I would like to receive a copy of your announcement or invitations to industry participants and any proceedings, reports, or briefings that resulted from the workshop.

The reason for my interest is that I am facilitating a major ARPA study of large water-based wing-in-ground-effect craft. These craft have many of the same features and problems as seaplanes. I anticipate that some of the results of your workshop may be useful to our study.

You may reach me at my office in Seattle by calling (206) 443-1014.

Sincerely,

Roger W. Gallington

Roger W. Gallington, Ph.D.
Assistant Vice-President

c: file

Aerospace Industries Association

Office of Civil Aviation

Facsimile Transmission
Fax: 202/371-8470

Date:	September 24, 1993	From:	Bob Robeson Vice President Civil Aviation 202-371-8415
Pages:	Cover + 3		
To:	Roger Gollington, SAIC 206-448-6813		

With reference to your fax to me yesterday, I am attaching a copy of the meeting announcement. AIA's role was limited to making the meeting arrangements, and at this time the only other support that we expect to provide is to put any of our interested companies in contact with NAVAIR. I am forwarding a copy of your request to Curt Snyder, who can provide information to you. Curt can be reached at 703-692-7393 ext. 6310. I hope this answers your needs. If I can be of further assistance, please let me know.

Sincerely

Aerospace Industries Association

September 7, 1993

Robert E. Robason, Jr.
Vice President
Civil Aviation
(202) 371-8415

Dr. Manny Lores
Director of Systems Development
Lockheed Aeronautical Systems Company
Dept 73-01, Zone 06-70
86 South Cobb Drive
Marietta, GA 30063

Dear Dr. Lores:

As a consequence of the publication of the whitepaper "...From the Sea," a Navy-Marine Corps team has an intense interest in amphibious warfare at locations distant from the U.S. In considering possible vehicles for force deployment, a question has been raised as to the feasibility of developing a large jet seaplane able to transport a USMC fighting force to an overseas troublespot.

However attractive such an aircraft might be to the tactical planners, it is unlikely that the Navy or the Department of Defense could finance the cost of developing such a restricted use aircraft with a limited production run. Thus the acquisition strategy being discussed informally among military planners assumes:

1) The seaplane is a variant of a large commercial land-based transport;

2) Common production line;

3) Funding mainly through conventional commercial practices rather than through DOD sources.

The broad requirements under discussion are:

MTOW:	1,000,000 lbs
Capacity:	600,000 lbs
Range:	8,000 miles
Other:	Able to land the payload directly onto the beach or transfer the troops/equipment onto amphibious assault ships at sea.

In light of the interest expressed by your company in assessing the feasibility of this concept, you are invited to attend a one-day workshop sponsored by AIA beginning at 8:30 am on September 23. The format for the workshop is informal, with open discussion following the attached agenda. Government representatives will be asked to discuss progress toward defining an operational requirement. This workshop is intended to provide only a first-order assessment of technical feasibility. Any decision to pursue more detailed, configuration-specific studies will be the responsibility of the companies, and not AIA.

We expect to conclude by mid-afternoon. Because AIA conference rooms are unavailable on that date, the workshop will be hosted by McDonnell Douglas, 1735 Jefferson Davis Hwy, Suite 1200, Arlington, VA. If you need additional information you can call me at (202) 371-8415 or Curtis Snyder at (301) 826-1133.

Sincerely,

Bob Robeson

Robert E. Robeson, Jr.

cc: John Honrath
Chuck Miller

Advance Agenda
AIA Sponsored Workshop on Landplane/Seaplane Co-Production

September 23, 1993

0830	Welcome - Mr. Robeson, AIA Vice President for Civil Aviation
0845	Introduction - Mr. Curtis Snyder, NAWCAD Patuxent River
0900	History of Navy Seaplane interests - Mr. Kobitz (OP911)
1000	Joint Littoral Warfare Seaplane - Mr. Tomayko (OP911) (input to T16 Wargame)
1030	Relevant ONR Technology Programs - Mr. King, ONR
1100-1200	Roundtable Discussions of Seaplane Viability All in a fiscally constrained environment
1200-1300	Lunch
1300-1430	Roundtable Discussions of Co-Production Feasibility - the industry viewpoint
1430-1500	Wrap-up USAF perspective - NASA interests - Action items
1515	Adjourn

National Aeronautics and
Space Administration
Headquarters
Washington, DC 20546-0001

July 11, 1994

Reply to Attn of: RF

TO: Distribution

FROM: Manager, Flight Research and Technology
High Performance Aircraft and Flight Projects Division
NASA Headquarters Office of Aeronautics

SUBJECT: Russian Wingship Proposal Evaluation

Col. Mike Francis (ARPA) asked NASA to contract for up to $500,000 of Russian Wingship technology studies and workshops in early 1994. NASA signed a Purchase Order on June 6, 1994 with Russian American Science, Inc. (American company) to acquire proposals for Russian studies and informational workshops. The Russian proposals are expected on July 25, 1994. The proposals are in response to a draft Set-Aside Request for Proposals which was hand delivered to the Russians in March 1994 by Col. Francis.

Your help in reviewing, rating, and ranking the Russian proposals is requested. A kickoff meeting will be held at NASA Headquarters on July 27, 1994. You will be briefed on background information including the outcome of a similar request for proposal dated March 15, 1994, which resulted in the award of four study contracts to U.S. industry. On July 27, 1994, you will be given a copy of the Russian proposals including draft rating sheets for your consideration. Then we will meet again on August 2 and 3, 1994 to discuss and develop ratings and final ranking of the proposals.

If you have questions, please call me at 202-358-4623. Thank you for agreeing to serve in this proposal evaluation activity and I look forward to seeing you on July 27, 1994.

John Lutes

John Lutes

Enclosure: Proposal Evaluation Schedule

Distribution:
Proposal Evaluation Team Members
RN/Isaiah Blankson
RH/Robert Mercure
LaRC/Dennis Bushnell
NSWC-CD (Carderock)/Bob Wilson
NSWC-CD (Carderock)/Jim Camp
NAWC-AD (Warminister)/John Reeves

Program Addressees
ARPA/Col. Mike Francis
SRS/Dick Jones
NSWC-CD/Steve Wells
SAIC/Roger Gallington

PROPOSAL EVALUATION SCHEDULE

RUSSIAN WINGSHIP TECHNOLOGY SET-ASIDE PROGRAM

NASA Headquarters
400 E Street S.W.
Washington, D.C. 20546

Exit L'Enfant Subway Station at 7th and D Streets (DOT Bldg.)
Walk Eastward along E Street to the new NASA Bldg.
Call X4623 at front desk for clearance

July 27, 1994 (NASA Hq. Rm MIC-6B) **Pass out copy of proposals & scoring sheets**

1000-1010	Welcoming Remarks	John Lutes
1010-1030	Program Overview	Col Mike Francis
1030-1130	Results of U.S. BAA Process	Steve Wells
1130-1200	Evaluation Remarks	John Lutes

August 2, 1994 (NASA Hq. Rm 2063) **Rate and rank the proposals**

1000-1200	Discuss/Rank Proposals	All
1200-1300	Lunch	
1300-1600	Discuss/Rank Proposals	All

August 3, 1994 (NASA Hq. Rm 2063) **Develop final ranking of proposals**

0900-1200	Discuss/Rank Proposals	All
1200-1300	Lunch	
1300-1600	Discuss/Rank Proposals	All

The number or length of Russian proposals which we may receive was unknown at the time this was prepared. Therefore, above schedule may need to be either shortened or extended after proposals are received and examined on July 25, 1994.

Wingship Investigation

Other Approaches to Heavy Equipment Rapid Delivery

Appendix B

B. OTHER APPROACHES TO HEAVY EQUIPMENT RAPID DELIVERY

The Department of Defense possesses plans for the rapid delivery of heavy equipment in time of need. These plans and capabilities have recently been tested in the field during Operation Desert Shield. Partly as a response to the experience of Operation Desert Shield and Operation Desert Storm, the Department of Defense authorized the Mobility Requirements Study. Requirements for the rapid deployment of forces were established, and actions were directed to modify national policy. An ARPA funded program has begun which addresses the general rapid deployment capabilities of the U. S., and some other studies have been started.

This appendix discusses briefly the MRS document, the present status of deployment capabilities for heavy Army divisions, and several approaches to the rapid delivery of heavy equipment which do not employ wing in ground effect vehicles.

MRS Summary. The Department of Defense has sponsored the Mobility Requirements Study (MRS), in part, to establish guidelines for deploying heavy Army divisions as part of a short term response. See section 6.4 of this report for a more complete discussion of the MRS. The requirements set in the MRS were based on accepting no more than moderate risk to the attainment of U. S. objectives. The MRS requirements include deploying the following within the early risk period (i.e. within two weeks of a decision date):

- an Army heavy brigade
- Army light forces
- combat support and combat service support.

The MRS requirements also include deploying heavy Army divisions within eight weeks of a decision date.

The DoD integrated mobility plan stated in the MRS includes plans to mitigate early risk by taking action in three areas. First, increasing airlift capability will be addressed by continuing the C-17 program. Second, increasing sealift capability will be addressed by

- acquiring and deploying container ships
- deploying by 1997 an afloat pre-positioned package for army combat and support equipment
- adding by 1998 sealift capability for rapid deployment of heavy Army divisions
- expanding the ready reserve sealift force.

Third, improving the U. S. internal transportation system for moving heavy equipment to U. S. staging locations.

Rapid Deployment as of 1990 for ODS. The rapid deployment capabilities of the U. S. for the start of Operation Desert Storm were directed by the two arms of the Department of Defense U. S. Transportation Command: The Military Sealift Command (MSC) and the Military Airlift Command (MAC). Ship transportation is the most important method for delivering heavy equipment. The MSC has established three categories of ships: the active fleet of military sealift

command transports, a fleet of fast sealift ships (converted commercial transports), and a ready reserve fleet of 96 older cargo ships which can be activated in roughly 20 days.

During Operation Desert Shield 2.3 tons of cargo was delivered with the following breakdown into transportation categories:

32%	pre-positioned ships
14%	Fast Sealift Ships
5%	Civil Reserve Air Fleet
18%	Military Air Command Aircraft
31%	Ready Reserve Fleet.

All heavy equipment was delivered either by ship or by military aircraft. The U. S. forces were drawn from around the world. The transport ships employed were: 21 pre-positioning ships, 8 fast sealift ships, 43 ready reserve fleet ships, and 110 other MSC and leased ships. Roughly five weeks after the beginning of the deployment process, 35 ships had arrived in Saudi Arabia and another 75 ships were enroute. This was reported to be approximately two weeks behind schedule. It required several weeks to deploy heavy armor divisions.

Container Ships. The MRS report suggests that the U. S. obtain at least two container ships for rapid delivery of heavy equipment. The current fleet of, for example, Hyundai Merchant Marine Co. container ships requires 18 days of transit time between Los Angeles and Hong Kong. Its new generation container ships require 13 days transit time between Los Angeles and Hong Kong, and have a capacity of over 4400 TEU.

ARPA Sponsored Mobile Base Program. ARPA is currently sponsoring a small program consisting of two studies through the Naval Surface Warfare Center in Carderock, Md., for the rapid deployment of heavy equipment.

The first of these studies is considering building a 3000 foot long floating runway and storage area for pre-positioning heavy equipment. A performance characterization is currently being done. At this very preliminary stage in the study, the structure being considered may be employed to pre-position as much as one heavy army division. The structure is likely to be mobile - movable to a new position on the order of several weeks.

The second study is concerned with converting a 400000 square foot very large crude carrier to military use. This concept would allow moving 1/9 of a heavy Army division. The baseline vehicle used for the study has a cruising speed of about 16 knots.

This program plans to continue into FY94 with studies for offshore basing, portable ports, and re-configurable craft. The total level of funding is to be about .

HERDS Study. A study for a Heavy Equipment Rapid Delivery System (HERDS) was undertaken by the company ISAT in 1991, and more recently continued by W. J. Schafer

Associates. This concept would use large unmanned gliders, towed by civilian aircraft (CRAF), to deliver heavy equipment close to their deployment positions. The hoped for performance of this system would give delivery of one heavy army division in less than half the delivery time now needed by surface ships. Its planned cost per glider would be one fourth the cost of the C-17 at production levels. Each glider would carry 60 tons, and would travel at Mach 0.7 when pulled by a 747, say.

Wingship Investigation

WIG Parametric Study

CONTENTS

Appendix C

C.1 VEHICLE SIZING METHODOLOGY

Sizing analysis is an integrated multi-discipline which defines a vehicle meeting a given set of requirements. The disciplines involved in this study are: configuration synthesis; mass properties estimation; aerodynamics; propulsion; and performance estimation. Range is a fallout which provides a quantitative measure of merit for the sized vehicles.

WIG IBM PC PROGRAM

The weight prediction equations were combined with the aerodynamics, performance, geometry and propulsion equations in a weight/performance computer program. This program generates a matrix of several hundred vehicles configurations of varying aspect ratio, wing loading, taper ratio, gross takeoff weight, payload fraction, and engine scale factor, while automatically adjusting vehicle geometry as required. Outputs include range, endurance, number of engines required, and other performance parameters of interest. The program also outputs a MIL-STD-1374A Group Weight Statement for any configuration, if desired. Configuration selection was done by inspection of this data. The primary criterion for selection was range; however, a small penalty in reduced range was accepted if it resulted in a significant reduction in the number of engines required.

A flow diagram for the program is presented in Figure C-1. Geometric parameters and other parameters of the reference vehicle (SPASATEL) are input, together with any parameters of the derivative vehicle which differ from those of the reference vehicle. Normally these will be limited to aspect ratio, wing loading, taper ratio, gross takeoff weight, and payload fraction. The Geometry Module calculates the geometry of the derivative vehicle. The PAR module calculates the total thrust required for takeoff. The Propulsion Module determines the number of engines required, engine scale factor, engine weight, number of engines operating during WIG cruise, fan length, engine diameter, takeoff fuel required, and cruise fuel flow rate. The Weights Module calculates the MIL-STD-1274A group weights, weight empty, operating weight, and total usable fuel available.

The Aero Module determines the vehicle cruise aerodynamic lift-to-drag ratio (L/D). Drag of the non-operating engines at cruise due to feathered fan blades is book-kept into the specific fuel consumption. In a typical case, the aerodynamic L/D displayed may be 24% higher than an L/D value adjusted to include this drag. The Performance Module calculates range, endurance, and Mach number. Cruise performance calculations account for the decreasing gross weight and speed of the vehicle as fuel is consumed. L/D is held constant. This process is illustrated by the equations shown in Section C. The program accommodates both in and out-of-ground effect operation.

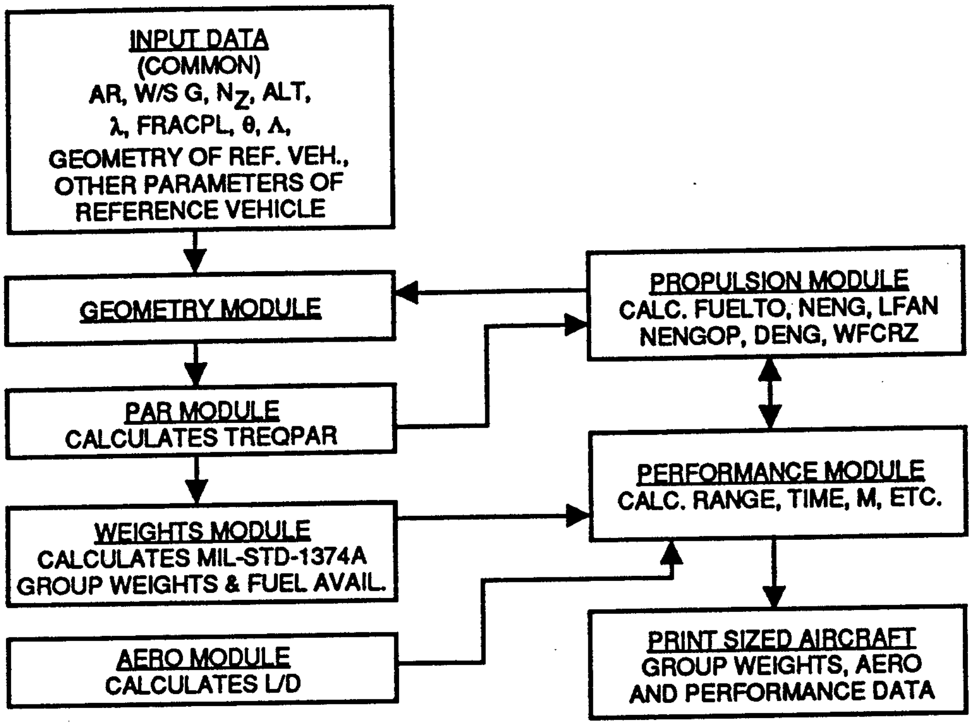


Figure C-1. Vehicle Sizing Program Flow Diagram

ANALYSIS PROCEDURE

The analysis procedure in this study is as follows:

1. For a given GW and PL/GW fraction, select vehicle from a parametric analysis of AR and wing loading. An example tabulated sizing analysis is shown in Figure C-2 for a GW = 10M pounds and PL/GW = 0.2.

2. Expand the parametric results for a large range of GW and PL/GW values. The results are tabulated in Figure C-2 and plotted in Figure C-3.

3. Select a vehicle from the parametric study and show sensitivity for parameters that have large impact on vehicle design. The sensitivities were calculated for a GW = 10M pounds and PL/GW = 0.2. The results are shown in the form of plots (see figures in Section C.8).

Figure C-2. Parametric Sizing Characteristics

GW LB	PL/GW	AR	W/S PSF	RANGE NM	NO. ENG TO/CR	T/W	M	L/D	h/b	We/GW	FUEL FRTN	CRUISE SFC	ENG SCALE
1M	0.1	3.5	200	5820	2/2	0.26	0.52	19.2	0.091	0.42	0.48	0.54	1.24
4M	0.1	4.0	275	9500	8/4	0.26	0.55	25.7	0.050	0.35	0.55	0.56	1.24
7M	0.1	4.0	300	11230	14/6	0.25	0.56	28.4	0.039	0.32	0.58	0.56	1.18
10M	0.1	4.0	300	12410	18/8	0.23	0.55	30.9	0.033	0.31	0.59	0.56	1.24
1M	0.2	2.5	175	2620	2/2	0.26	0.52	15.2	0.100	0.48	0.32	0.55	1.24
4M	0.2	3.0	225	4880	8/4	0.26	0.53	21.5	0.052	0.41	0.38	0.55	1.24
7M	0.2	3.0	250	5960	14/8	0.25	0.55	23.7	0.042	0.39	0.41	0.56	1.17
10M	0.2	3.0	250	6685	18/8	0.23	0.54	25.8	0.035	0.38	0.42	0.56	1.24
1M	0.3	2.5	200	525	4/4	0.32	0.54	13.7	0.107	0.56	0.13	0.55	0.76
4M	0.3	2.5	200	2090	8/6	0.25	0.52	19.2	0.054	0.47	0.22	0.55	1.20
7M	0.3	2.5	250	2780	14/8	0.26	0.57	20.2	0.045	0.44	0.26	0.57	1.24
10M	0.3	2.5	275	3220	20/10	0.26	0.59	21.3	0.040	0.43	0.27	0.58	1.24

MATERIAL FACTOR = 0.8
P&W 4084/82K INSTALLED THRUST (ENG SCALE = 1.0)
INCLUDE FAN AUGMENTATION
VARIABLE PITCH FAN CAPABILITY
ALL A/C CAPABLE OF FLIGHT OUT OF GROUND
10M A/C BASIS OF SENSITIVITY STUDY (APPENDIX)

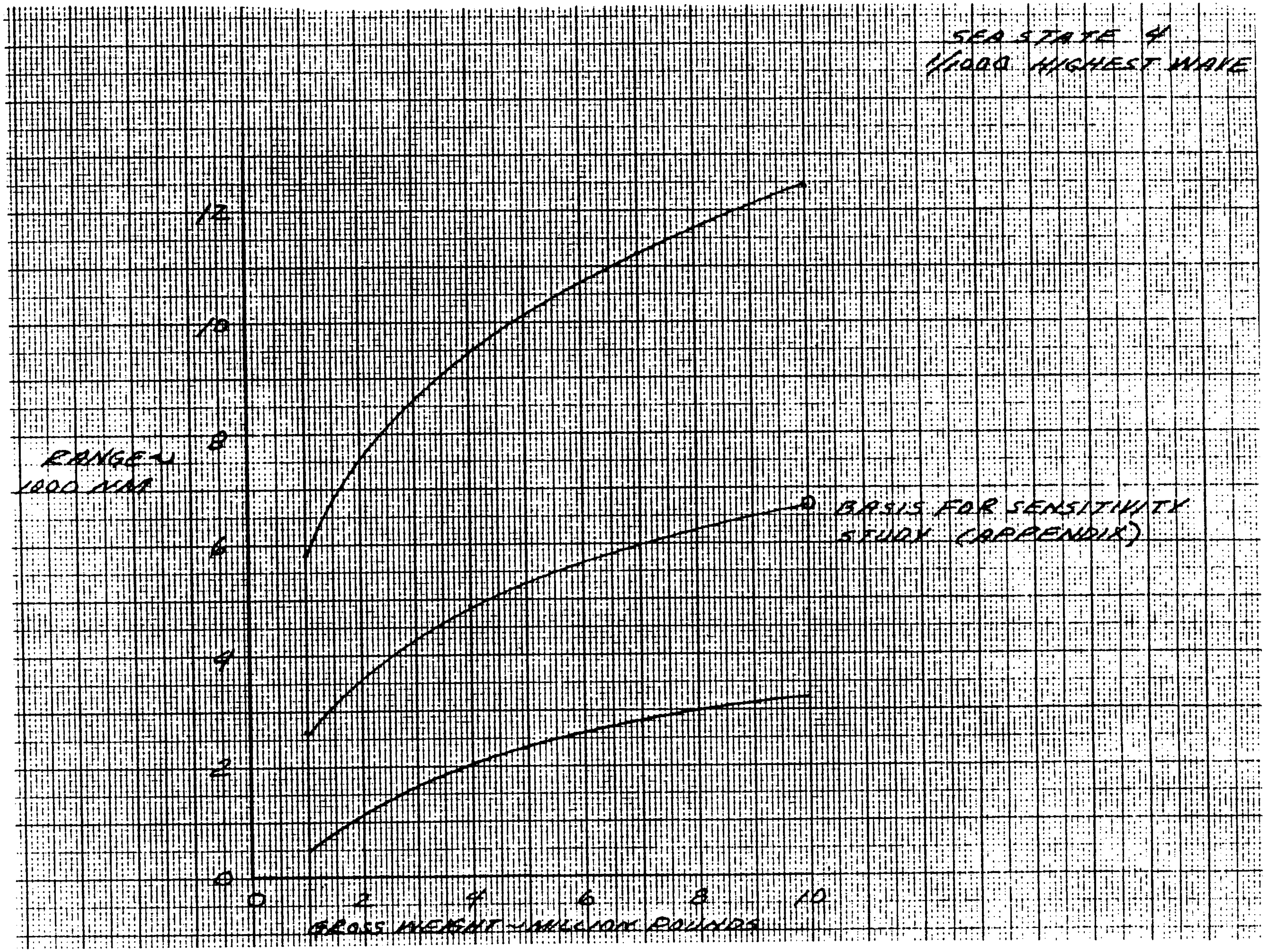


Figure C-3. Parametric Sizing Results

C.2 GEOMETRY MODULE

FUSELAGE GEOMETRY

Fuselage geometry was based on the SPASATEL geometry. The configuration geometry equations are presented in Figure C-4. Length/width ratio and depth/width ratio were held constant. Width was varied directly with the 1/3 power of the payload weight in order to maintain an invariant cargo compartment density.

WING GEOMETRY

Wing geometry for a given configuration was determined by the wing loading and aspect ratio that gave the best range, and the gross weight, and taper ration. The 0.63 taper ratio of the SPASATEL vehicle was used for all configurations.

TAIL GEOMETRY

The horizontal tail area was assumed to be 40.6% of the wing area, and the vertical tail area 21.1%, as in the SPASATEL vehicle.

C.3 WEIGHT PREDICTION MODULE

The weight prediction equations used were Level II parametric equations obtained by constrained regression analysis of a database consisting of large military cargo aircraft. They are standard Northrop equations are presented in Figure C-5. These equations were indexed to the weights shown in the Wingship Compendium document (A. Naskalik and V. Treschevsky, 1992, Appendix V, page 308), for the 880,000 lb SPASATEL aircraft.

Index factors required were high, (e.g., 2.09 on the Wing Group, 1.38 on the Fuselage Group, etc.) Material factor was set at 1.0 for indexing and reduced to 0.8 for the parametric studies. The 0.8 reduction factor for structural materials weights is intended to account for materials and possess technology advancement and is construed to be justified by US, R&D activities, e.g., numerous composites programs.

C.4 POWER AUGMENTED RAM MODULE

The thrust requirement for takeoff is based on the envelope of experimental data from NASA (1972) and DTNSRDC (1976). Takeoff is based on the PAR parameter Lh/TC of approximately 0.56. Thrust requirement is based on the same T/W level as the SPASATEL and is the wing height with the vehicle at a nominal attitude and the aft end of the hull in surface contact. Two thirds of the installed thrust is assumed to be available for acceleration in the PAR mode. A simple formulation of this calculation is contained in Figure C-6.

$$S_W = TOGW/LOADING$$
$$b = [(AR)(SW)]^{0.5}$$
$$C_{AVG} = S_W/b$$
$$C_R = \frac{2\ (S_W)^{0.5}}{(1+\lambda)\ (AR)^{0.5}}$$
$$C_T = C_R(\lambda)$$
$$H_{PLATE} = 0.05\ (b)$$
$$SWTP = C_T\ (1.2)\ (H_{PLATE})\ (2)$$
$$B_o = 0.152\ (TOGW)^{0.3333}\ (FRACPL/0.206)^{0.3333}$$
$$L_a = B_o\ (L_a/B_o)$$
$$D_o = B_o\ (D_o/B_o)$$
$$S_v = 0.211\ (S_W)$$
$$S_H = 0.406\ (S_W)$$
$$S_F = 1.227\ (L_a)\ (B_o + D_o)\ [1+0.0992\ (B_o/D_o)] - 85$$
$$HPAR = 0.6\ (La)[TAN(\theta)]$$
$$S_{WETENG} = [2\ D_e N_{STACK} + 2.05\ N_e D_e/N_{STACK}]\ [L_{FAN}]$$
$$S_{WET} = 2.06\ S_W + 2.06\ S_H + 2.06\ S_v + S_F + S_{WETENG} + 2\ SWTP$$
$$b = (S_W * AR)^{0.5}$$
$$b_H = b$$
$$C_{TV} = C_{TVREF}\ (S_V/S_{VREF})0.5$$

Figure C-4. Geometry Equations

INPUTS

LOADING	TOGW/S_W
TOGW	Takeoff Gross Weight, lb
AR	Aspect ratio, wing
λ	Taper ratio, wing
FRACPL	WPAYLOAD/TOGW
L_a/B_o	Fuselage length/width ratio (14.42)
D_o/B_o	Fuselage depth/width ratio (1.58)
θ	Angular displacement of HRP with respect to local horizontal, degrees, (2.6)
D_e	Installed max diameter of engine, ft
N_{STACK}	No. of rows of engines (when stacked)
N_e	No. of engines
L_{FAN}	Length of inlet plus fan duct, ft
C_{TVREF}	Tip chord of vertical tail on reference aircraft, ft
S_{VREF}	Area of vertical tail on reference aircraft, sq ft

CALCULATED VALUES

S_W	Area, wing, gross, ft^2
b	Span, wing, ft
C_{AVG}	Average chord, wing, ft
C_R	Root chord, wing, ft
C_T	Tip chord, wing, ft
H_{PLATE}	Vertical dimension of tip plate, ft
SWTP	Planform area of (2) tip plates, ft^2
B_o	Width of fuselage, ft
L_a	Length of fuselage, ft
D_o	Depth of fuselage, ft
S_V	Area, vertical tail, ft^2
S_H	Area, horizontal tail, ft^2

Figure C-4. Geometry Equations (Continued)

CALCULATED VALUES (Cont.)

S_F	Wetted area, fuselage, ft^2
HPAR	Vertical distance from lowest point on wing tip-plate to reference water surface (PAR mode), ft
S_{WET}	Total wetted area of aircraft, ft^2
b_H	Span, horizontal tail, ft
C_{TV}	Tip chord, vertical tail, inches
S_{WETENG}	Wetted area, nacelles, total, ft^2

Figure C-4. Geometry Equations (Continued)

WING GROUP

$$IW2 \quad \frac{GN_Z\ b\ AR\ (\frac{1+2\lambda}{1+\lambda})}{\cos\ \Delta_{c/4}\ [3(t/c)_R + (t/c)_T]/4} \times 10^{-6}$$

$$W_W = [C_{WING}\ (S_W)^a\ (IW2)^b\ K_{CS}\ K_{WS} + WTP]\ K_{MATL}$$

$$WTP = K_{WTP}\ (S_{WTP})$$

INPUTS

G	Flight Design Gross Weight, lb
N_Z	Ultimate load factor
b	Span, wing, ft
AR	Aspect ratio, wing
λ	Taper ratio
$\Delta_{c/4}$	Sweep angle, quarter chord, degrees
$(t/c)_R$	Thickness ratio, root
S_W	Wing area, gross, sq ft
K_{CS}	Factor to index equation to the Lockheed C5-B, (1.11)
K_{WS}	Factor to index equation to reference wing ship, (1.88)
K_{MATL}	Material factor, (0.8)

Figure C-5. Weight Prediction Equations

CALCULATED VALUES

IW2	Loading term
WTP	Weight of wing tip plates, lb
S_{WTP}	Planform area of tip plates, per ship, sq ft
W_W	Wing Group weight, lb

Note: In the automated-geometry mode some of the geometry shown as inputs are calculated values. (See Geometry equations)

FUSELAGE GROUP

$$W_F = C_{FUS} (S_F)^a (K_C D_o L_a W_{CB} N_Z \times 10^{-6})^b K_{WS} K_{MATL}$$

$$WCB = TOGW - W_W - W_{FUEL}$$

$$K_C = 0.3634 (1.75178 + B_o/D_o), \text{ when } B_o/D_o \leq 1.0$$

$$K_C = 0.6366 (0.57082 + B_o/D_o), \text{ when } B_o/D_o \geq 1.0$$

INPUTS

L_a	Length, fuselage, ft
B_o	Width, fuselage, ft
D_o	Depth, fuselage, ft
K_{MATL}	Material factor, (0.8)
N_Z	Ultimate load factor
K_{WS}	Factor to index equation to reference wingship (1.38)
TOGW	Takeoff Gross Weight

CALCULATED VALUES

WCB	Weight of body and contents, lb
S_F	Wetted area, fuselage, sq ft
K_C	Shape factor, fuselage
W_F	Weight of Fuselage Group, lb
W_{FUEL}	Weight of usable fuel, lb
W_W	Weight of Wing Group, lb

Figure C-5. Weight Prediction Equations (Continued)

EMPENNAGE

$W_H \quad = [C_1 (S_H)^a + C_2 (C_{TV})] (K_{CSH}) (K_{WSH}) (K_{MATL})$

$W_V \quad = C_V (S_V)^a (K_{CSV}) (K_{WSV}) (K_{MATL})$

INPUTS

C_{TV}	Tip chord, vertical tail, inches
K_{CSH}	Factor to index equation to C5-B, (1.03)
K_{WSH}	Factor to index equation to reference wingship, (1.65)
K_{CSV}	Factor to index equation to C5-B, (1.00)
K_{WSV}	Factor to index equation to reference wingship, (2.5)
K_{MATL}	Material factor, (0.8)

CALCULATED VALUES

W_H	Weight of horizontal tail, lb
S_H	Area of horizontal tail, ft
W_V	Weight of vertical tail, lb
S_V	Area of vertical tail, sq ft

LANDING GEAR (Hydro-Ski)

$W_{HS} \quad = C_1 L_a B_o$

INPUTS

L_a	Length, fuselage, ft
B_o	Width, fuselage, ft

CALCULATED VALUES

W_{HS}	Weight, hydro-ski, lb

ENGINE SECTION (Caravelle Type)

$W_{ESA} \quad = C_1 (W_e)^a (T)^b (N_Z)^c (N_e) (K_{WSES})$

Figure C-5. Weight Prediction Equations (Continued)

INPUTS

W_e	Weight of engine, lb/ea. (incl. nozzle)
N_Z	Ultimate load factor
K_{WSES}	Factor to index equation to reference wing ship, (2.91)

CALCULATED VALUES

T	Thrust of (1) engine, lb/ea.
N_e	Number of engines
W_{ESA}	Weight of Engine Section group, lb

PROPULSION GROUP

$$W_p = C_1 (W_e N_e)^a K_{WSP}$$

INPUTS

W_e	Weight of engine, lb/ea. (incl. nozzle)
K_{WSP}	Factor to index equation to reference wingship, (2.32)

CALCULATED VALUES

N_e	Number of engines
W_p	Weight of Propulsion Group, lb

FIXED EQUIPMENT

$$W_{FC} = C_1 [(L_a + \frac{b}{\cos\Delta_{c/4}}) GN_Z\, q \times 10^{-6}]^a \; (1.5)$$

$$W_{INSTR} = C_1 (N_c)^a (N_e) (L_a + \frac{b}{\cos \Delta_{c/4}})^d$$

$$W_{APU} = C_1(G)^a, \text{ or 1600 lb, whichever is less}$$

Figure C-5. Weight Prediction Equations (Continued)

FIXED EQUIPMENT (Cont.)

W_{HYD} $= C_1(G)^a + C_2(G)^d + C_3(G)^f (L_a+b)(2)$

W_{ELECT} $= C_1 (KVA)^a (L_a + \frac{b}{\cos \Delta_{c/4}})^d$

W_{AV} $= C_1(G)^a$, or 4000 lb, whichever is less

W_{FURN} $= C_1 L_a + C_2N_e + C_3S_W + (W_2 + N_C/4) + 3200$

W_{ECS} $= [(C_1N_c + C_2 M_n + 1.25 (W_{AV})^a + 10{,}000)^b \times 10^{-4}] K_{ECS}$

W_{AI} $= C_1 + C_2 N_e + C_3 (\frac{b}{\cos \Delta_{c/4}}) + C_4 [\frac{b_H}{\cos \Delta_H} + \frac{b_V}{\cos \Delta_v}]$

W_{LH} $= C_1 (G)$

KVA $= C_1 (W_{AV})^a (L_a)^d (N_c) + C_1(G)^f$

W_{EQ} $= W_{FC} + W_{INSTR} + W_{APU} + W_{HYD} + W_{ELECT} + W_{AV} + W_{FURN} + W_{ECS} + W_{AI} + W_{LH}$

INPUTS

G	Flight Design Gross Weight, lb
N_Z	Ultimate load factor
L_a	Length, fuselage, ft
N_c	Number of crew
S_W	Area, wing, gross, sq ft
Δ_H	Sweep angle of leading edge, horizontal tail, degrees
Δ_V	Sweep angle of leading edge, vertical tail, degrees
$\Delta_{C/4}$	Sweep angle of wing quarter-chord, degrees

CALCULATED VALUES

b	Span, wing, ft
q	Dynamic pressure, lb/ft^2

Figure C-5. Weight Prediction Equations (Continued)

CALCULATED VALUES (Cont.)

M_n	Mach no.
N_e	Number of engines
b_H	Span, horizontal tail, ft
b_V	Span, vertical tail, ft
W_{FC}	Weight, Flight Controls group
W_{INSTR}	Weight, Instrumentation group
W_{APU}	Weight, Auxiliary Power System
W_{HYD}	Weight, Hydraulic group
W_{ELECT}	Weight, Electrical group
W_{AV}	Weight, avionics, installed
W_{FURN}	Weight, Furnishings group
W_{ECS}	Weight, Air Conditioning group
W_{AI}	Weight, Anti-icing group
W_{LH}	Weight, Loading and Handling group
KVA	Power requirement, electrical, kilovolt-amps

OPERATING WEIGHT EMPTY ITEMS

$$WC = 200\ N_c$$
$$W_{OIL} = 75\ N_e$$
$$W_{UNF} = 0.01\ W_{FUEL}$$
$$W_{ME} = 500\ N_c$$
$$W_{PLP} = 11.5\ L_a$$
$$W_{OPER} = W_c + W_{OIL} + W_{UNF} + W_{ME} + W_{PLP}$$

INPUTS

N_c	Number of crew
N_e	Number of engines
L_a	Length, fuselage, ft

Figure C-5. Weight Prediction Equations (Continued)

CALCULATED VALUES

W_{UNF}	Weight, unusable fuel, lb
W_C	Weight, crew, lb
W_{OIL}	Weight, oil, lb
W_{ME}	Weight, miscellaneous equipment, lb
W_{PLP}	Weight, payload provisions, lb
W_{OPER}	Summation of Operating W.E. items, lb
W_{FUEL}	Weight, usable fuel, lb

USABLE FUEL

$$WSTRUCT = W_W + W_f + W_H + W_V + W_{HS} + W_{ESA}$$

$$WPAYLOAD = (FRACPL)(TOGW)$$

$$WEMPTY = WSTRUCT + W_P + WEQ$$

$$WFUEL = TOGW - WOPER - WPAYLOAD - WEMPTY$$

INPUTS

TOGW	Takeoff Gross Weight, lb
FRACPL	Ratio, payload weight to TOGW

CALCULATED VALUES

WPAYLOAD	Weight of payload, lb
WOPER	Summation of Operating W.E. items, lb
WEMPTY	Weight Empty, lb
WFUEL	Weight, usable fuel, lb
W_{EQ}	Weight, Fixed Equipment, lb
W_W	Weight, Wing Group, lb
W_F	Weight, Fuselage Group, lb
W_H	Weight, horizontal tail, lb
W_V	Weight, vertical tail, lb
W_{HS}	Weight, hydro-ski, lb

Figure C-5. Weight Prediction Equations (Continued)

CALCULATED VALUES (Cont.)

W_{ESA}	Weight, Engine section, lb
W_{STRUCT}	Weight, Structure, lb
W_P	Weight, Propulsion Group, lb
W_{EQ}	Weight, Fixed Equipment, lb
W_{OPER}	Summation of Operating W.E., items, lb

Figure C-5. Weight Prediction Equations (Continued)

$$HPAR = 0.6\,(L_a)\,(\mathrm{TAN}\,\theta)$$

$$TREQPAR = \frac{TOGW\ (HPAR)}{KPAR\ (C_{AVG})\ (0.67)}$$

INPUTS

L_a	Length of fuselage, ft
θ	Angular displacement of HRP with respect to the local horizontal, degrees, (2.6)
KPAR	Input value of $TOGW(HPAR)/(TREQPAR \cdot C_{AVG})$, from chart, (0.56)
TOGW	Takeoff Gross Weight, lb

CALCULATED VALUES

HPAR	Vertical distance from lowest point on wing tip-plate to reference water surface, ft
TREQPAR	Total thrust requirement in PAR mode, lb
C_{AVG}	Average chord, wing, ft

Figure C-6. Power Augmented RAM Equations

C.5 PROPULSION SYSTEM CHARACTERISTICS

The vehicle propulsion system consists of a number (even number) of Pratt and Whitney 4084 high bypass turbofan engines. Propulsion parameters are given in Figure C-7.

Estimated Properties:

Fan diameter: 112" Fan case diameter ≈ 120" Max diameter (w nacelle) ≈ 142" Engine length (flange-flange) = 192" Inlet duct length ≈ 72" Fan case length ≈ 72" Fan duct length (dry) ≈ 54" Total fan length ≈ 198" Bypass ratio ≈ 8 Rated airflow (W1 R) ≈ 2440 pps Inlet capture area ≈ 62 ft2 Weight (dry) ≈ 14,000# Estimated Installed Weight ≈ 15,5000# (no reverse) A bypass air "duct burner" has been proposed to provide increased thrust. Estimated effects include increasing fan length to ≈ 222", and increasing installed weight to ≈17,500#.

Engine Performance:

Bare performance data was obtained from P&W. This data was curve fit for use in a computer program. Operating envelope: Sea level and 5,000 ft (standard day) Mach number: 0.0 - 0.70

The average ratio of bypass gross thrust to total gross thrust (FGFAN /FGToT) ≈ 0.84.

Performance utilizing duct burning augmentation was estimated based on analysis performed by SRS Technologies, Arlington, VA, a company involved in propulsion analysis for the WIG project. With duct burning limits of 700°F for bypass air, the estimated increase in fan gross thrust is ≈ 35%, creating a total gross thrust increase ≈30%.

Cruise Performance:

Cruise thrust requirements are expected to be much less then the thrust available from all the engines. For this analysis, it is assumed that some engines will be shut down with feathered fan blades in cruise flight, and only those required to produce sufficient thrust for cruise will be operating (an even number). Engine cruise thrust performance should be maintained in the range of approximately 40% to 85% of max dry power. Duct burning is not utilized for cruise power. It is assumed that the variable fan blade feature would yield a 10% decrease in engine SFC due to more optimized engine performance. A weight penalty was included for this feature.

The drag (lb) created by non operating engines is book kept in the propulsion section, and included as part of the cruise thrust requirement. No additional performance losses are included to account for use of onboard APU systems, or engine bleed/power extractions.

$$THOB = (82000 - 76754 \cdot Xm + 32680 \cdot Xm^2) \cdot ENGSCL$$
$$TH5B = (71340 - 74786 \cdot Xm + 51102 \cdot Xm^2) \cdot ENGSCL$$
$$TSFCB = 0.335 + 0.31232 \cdot Xm + 0.1058 \cdot Xm^2$$
$$TSFC_{CRZ} = 1.15 \cdot TSFCB$$
$$FGQFN = 1.0 + 0.88 \cdot Xm + 2.10 \cdot Xm^2$$
$$FN_{MAX} = THOB + \frac{Alt}{5000} \cdot (TH5B - THOB)$$

$$FG_{max} = FN_{max} \cdot FGQFN$$
$$\Delta FG_{BURN} = FG_{max} \cdot (AUGQ-1)$$
$$FN_{BURN} = FN_{max} + \Delta FG_{BURN}$$
$$WF_{max} = FN_{max} \cdot TSFCB$$
$$WFBRN0 = (55000 - 1821.4 \cdot Xm + 38929 \cdot Xm^2) \cdot ENGSCL$$
$$WFBRN5 = (46500 - 1345.2 \cdot Xm + 32738 \cdot Xm^2) \cdot ENGSCL$$
$$WF_{TOT} = WF_{MAX} + WFBRN0 + \frac{Alt}{5000} \cdot (WFBRN5 - WFBRN0)$$

$$A_{CAP} = 62 \cdot \sqrt{ENGSCL}$$

$$ENDRAG = 0.12 \cdot q \cdot A_{CAP}$$
$$WF_{CRZ} = FN_{CRZ} \cdot TSFC_{CRZ}$$

<u>INPUTS</u>

Xm	Flight Mach Number
Alt	Flight altitude (ft) ≤ 5000'
ENGSCL	Engine Scale Factor 0.80 -1.20, typical
q	Flight dynamic pressure, psf
AUGQ	Burner gross thrust augmentation ratio (FG_{BURN}/FG_{DRY}) = 1.30

Figure C-7. WIG Propulsion Equations

CALCULATED (All calculations are per engine)

THOB	Max dry net thrust at sea level (lb)
TH5B	Max dry net thrust at 5000' (lb)
TSFCB	Thrust specific fuel consumption at max dry thrust (lb/hr/lb)
TSF_{CRZ}	Thrust specific fuel consumption at dry cruise power (lb/hr/lb)
FGQFN	Ratio of gross thrust to net thrust (Fg/Fn)
FN_{max}	Max dry net thrust (lb)
FG_{max}	Max dry gross thrust (lb)
ΔFG_{BURN}	Additional gross thrust due to duct burning augmentation (lb)
FN_{BURN}	Max net thrust with duct burning augmentation (lb)
WF_{max}	Fuel flow at max dry net thrust (lb/hr)
WFBRNO	Fuel flow for duct burning augmentation at sea level (lb/hr)
WFBRN5	Fuel flow for duct burning augmentation at 5000' (lb/hr)
WF_{TOT}	Total fuel flow at max thrust (lb/hr)
ACAP	Engine inlet capture area (ft^2)
ENDRAG	Drag of non-operating engine (lb)
WF_{CRZ}	Engine fuel flow at dry cruise power (lb/hr)
FN_{CRZ}	Engine net thrust at dry cruise power (40% - 85% of FN_{max}, typical)

Figure C-7. WIG Propulsion Equations (Continued)

C.6 AERODYNAMICS MODULE

The zero lift cruise drag of WIG parametric configurations is based upon conventional methods using component wetted area (wing, tail, fuselage, etc.), friction drag at the calculated flight Reynolds number from standard turbulent skin friction curves and appropriate additive form drag for each component. Drag due to lift is calculated using the Wieselsberger equation which will represent the induced drag of wings in the presence of a ground plane. The methods used to calculate the cruise lift-to-drag ratio for the parametric program are delineated below and in Figure C-8.

C.7 PERFORMANCE

Cruise fuel available was defined as total fuel available less 5% reserve fuel less takeoff fuel required. (See propulsion Equations for derivation of takeoff fuel requirement). For the purpose of range/endurance calculations the flight was divided into three cruise legs, each corresponding to one-third cruise fuel expended. Values of gross weight, velocity, drag, fuel flow rate, thrust and Mach number were calculated at the beginning and at the end of each leg. Average values were then used to calculate range and flight time for the leg. Total range was the sum of the ranges calculated for the three legs, less a 350 nm allowance to account for an alternate location for landing.

The equations in Figure C-9 show the calculations for the first leg. The second and third legs were calculated in a similar manner. WFCRZ and WFTO were taken from the Propulsion equations. The initial cruise speed was calculated for a given CL and wing area. As gross weight was reduced due to fuel burn-off cruise height and L/D were held constant and speed was reduced.

C.8 SENSITIVITY STUDIES

The baseline aircraft selected for sensitivity studies is a 1OM pound gross weight vehicle with a 0.2 payload fraction, and a 5,667 nm range. Figure C-10 tabulates a sub optimization for this vehicle and identifies the specific vehicle selected. Geometric parametric are wing aspect ratio 3.0; wing area 40,000 sq. ft; horizontal tail area 16,247 sq. ft; vertical tail area 8,425 sq. ft; wing span 346.4 ft; wing root chord 141.68 ft; wing tip chord 89.26 ft; wing thickness ratio 0.1; fuselage length 468.7 ft; width 32.50 ft; and depth 52.42 ft.

This configuration has 18 afterburning engines, of which 8 are operating during cruise. Engine diameter is 13.18 ft, and fan length is 18.50 ft. This is the vehicle that was used to study the various sensitivities that influence the design process. Its Group Weight statement is attached. (Figure C-11).

Sensitivities to significant parameters are presented in Figure C-12 through C-18. Included are sensitivities to vehicle range of wing aspect ratio, structural materials weight factor, design cruise height (sea state), out of ground effect cruise, payload fraction, engine performance parameters, wing loading and weight empty fraction.

$$X_{ALT} = 7.1 \times 10^6, \text{ if } ALT = 0$$

$$X_{ALT} = 6.18 \times 10^6, \text{ if } ALT \neq 0$$

$$RN_f = X_{ALT} (L_a)$$

$$C_{ffuse} = \frac{0.455}{1.025 \; (\mathrm{LOG}\; RN_f)^{2.58}}$$

$$\Delta C_{fefus} = 1.4 \; (C_{ffuse})$$

$$\Delta C_{Dofus} = \Delta C_{fefus} \; (S_F) \; / \; SW$$

$$RN_W = X_{ALT} \; (C_{AVG})$$

$$C_{fwing} = \frac{0.455}{1.025 \; (\mathrm{LOG}\; RN_W)^{2.58}}$$

$$\Delta C_{fewing} = 1.1 \; (C_{fwing})$$

$$\Delta C_{Dowing} = \Delta C_{fewing} \; (2.05)$$

$$C_{fe} = \frac{1.2 \; (\Delta C_{Dofus} + \Delta C_{Dowing}) \; (S_W)}{2.05 \; S_W + S_F}$$

$$C_{DOTOT} = C_{fe} \; (S_{WET} \; / \; S_W)$$

$$\sigma = 2.71828^{-2.48 \; (2 \; H_{WIG}/b)^{0.768}}$$

$$C_L = \sqrt{\frac{C_{DOTOT}(\pi)(AR)(0.85)}{1-\sigma}}$$

$$AR_{EFF} = \frac{AR}{1-\sigma}$$

$$C_{Di} = \frac{C_L^{\,2}(1-\sigma)}{\pi(AR)(0.85)}$$

Figure C-8. Aerodynamic Equations

$$\alpha_i = \frac{18.24\ (C_L)\ (1-\sigma)}{AR(0.85)}$$

$C_{DTOT} = C_{DOTOT} + C_{Di}$

$L/D = C_L / C_{DTOT}$

INPUTS

b	Span, wing, ft^2
AR	Aspect ratio, wing
H_{WIG}	Vertical distance from lowest point on wing tip - plate to water surface (cruise), ft
ALT	Cruise altitude, ft

CALCULATED VALUES

X_{ALT}	Reynolds Number per ft
RN_F	Reynolds Number, fuselage
C_{ffuse}	Friction drag coefficient, fuselage
ΔC_{fefuse}	Equivalent friction drag coefficient, fuselage
ΔC_{Dofuse}	Zero lift drag coefficient, fuselage
RN_W	Reynolds number, wing
C_{fwing}	Friction drag coefficient, wing
ΔC_{fewing}	Equivalent friction drag coefficient, wing
ΔC_{Dowing}	Zero lift drag coefficient, wing
C_{fe}	Total equivalent friction drag coefficient
C_{DOTOT}	Total zero-lift drag coefficient
σ	Ground effect parameter
C_L	Lift coefficient, total
AR_{eff}	Effective aspect ratio
C_{Di}	Total induced drag coefficient

Figure C-8. Aerodynamic Equations (Continued)

CALCULATED VALUES (Cont.)

α_i	Induced angle of attack, total
C_{DTOT}	Total drag coefficient
L/D	Lift/drag ratio
S_W	Area, wing, ft^2
S_F	Wetted area, fuselage, ft^2
C_{AVG}	Average chord, wing, ft
S_{WET}	Total wetted area of aircraft, ft^2

Figure C-8. Aerodynamic Equations (Continued)

$$GW_{INITCR} = TOGW - W_{FTO}$$

$$V_{INITCR} = \sqrt{\frac{GW_{INITCR}(295)}{C_L(S_W)}}$$

$$M_{INITCR} = V_{INITCR} / 661$$

$$D_{INITCR} = GW_{INITCR} / (L/D)$$

$$WDOT_{IC} = W_{FCRZ} (SERVTOL)$$

$$F_{CRPLUS} = W_{FUEL} - 0.05 (W_{FUEL}) - W_{FTO}$$

$$GW_{33PC} = GW_{INITCR} - F_{CRPLUS} / 3$$

$$V_{CR33PC} = \sqrt{\frac{GW_{33PC}(295)}{C_L(S_W)}}$$

$$M_{CR33PC} = V_{CR33PC} / 661$$

$$D_{CR33PC} = GW_{CR33PC} / (L/D)$$

$$WDOT_{33PC} = W_{FCRZ} (SERVTOL)$$

$$TIME_{33PC} = \frac{2\ (0.333)\ (F_{CRPLUS})}{WDOT_{IC} + WDOT_{33PC}}$$

$$DIST_{33PC} = TIME_{33PC} (V_{INITCR} + V_{CR33PC}) / 2$$

$$RANGE = DIST_{33PC} + DIST_{3367} + DIST_{LEG3} - 350$$

$$ENDUR = TIME_{33PC} + TIME_{3367} + TIME_{LEG3}$$

<u>INPUTS</u>

TOGW	Takeoff Gross Weight, lb
SERVTOL	Service tolerance factor, (1.05)
S_W	Wing area, ft^2

Figure C-9. Performance Equations

CALCULATED VALUES

GW_{INITCR}	Aircraft weight at initial cruise, lb
V_{INITCR}	Velocity at initial Cruise, knots
M_{INITCR}	Mach No. at initial cruise
D_{INITCR}	Drag at initial cruise, lb
$WDOT_{IC}$	Fuel flow rate, initial cruise, lb/hr
F_{CRPLUS}	Cruise fuel available at initial cruise, lb
GW_{33PC}	Aircraft weight at 1/3 cruise fuel expended, lb
V_{CR33PC}	Velocity at 1/3 cruise fuel expended, knots
M_{CR33PC}	Mach No. at 1/3 cruise fuel expended
D_{CR33PC}	Drag at 1/3 cruise fuel expended, lb
$WDOT_{33PC}$	Fuel flow rate at 1/3 cruise fuel expended, lb/hr
$TIME_{33PC}$	Time, start cruise to 1/3 cruise fuel expended, hr
$DIST_{33PC}$	Distance, start cruise to 1/3 cruise fuel expended, n.m.
RANGE	Distance, start cruise to end cruise, n.m.
ENDUR	Time, start cruise to end cruise, hr
W_{FTO}	Weight of takeoff fuel required, lb
C_L	Lift coefficient, total
W_{FCRZ}	Fuel flow rate, lb. Multiply by service tolerance to get WDOT. (Takes on different values for different cruise legs.)
L/D	Lift/draft ratio

Figure C-9. Performance Equations (Continued)

Figure C-10. Sizing Analysis for GW=10M lb

PL/GW = 0.2; MATERIAL FACTOR = 0.8; AUGMENTED THRUST

AR	W/S	RANGE	ENG TO/CR	T/W	M	L/D	h/b	ESF	
2.0	150	5750	12/10	0.15	0.48	23.6	0.033	1.16	
	200	6190	14/10	0.17	0.56	21.6	0.038	1.15	
	250	6300	16/12	0.19	0.62	20.0	0.042	1.13	
	300	6310	16/12	0.21	0.68	18.7	0.046	1.24	
2.5	150	5870	14/8	0.16	0.45	27.3	0.029	1.12	
	200	6360	16/10	0.19	0.52	24.8	0.034	1.13	
	250	6580	16/10	0.21	0.58	23.0	0.038	1.24	
	300	6550	18/10	0.23	0.63	21.5	0.042	1.24	
3.0	150	5920	14/6	0.18	0.42	30.6	0.027	1.24	
	200	6490	16/8	0.21	0.49	27.9	0.031	1.24	
	250	6680	18/8	0.23	0.54	25.8	0.035	1.24	Parametric choice
	300	6560	20/10	0.25	0.59	24.1	0.038	1.24	
3.5	150	5900	16/6	0.19	0.40	33.8	0.025	1.15	
	200	6520	18/8	0.22	0.46	30.8	0.029	1.18	
	250	6730	20/8	0.25	0.51	28.5	0.032	1.19	
	300	6750	22/8	0.27	0.56	26.6	0.035	1.19	
4.0	150	5850	16/6	0.21	0.38	36.8	0.023	1.24	
	200	6490	20/6	0.24	0.44	33.5	0.027	1.14	
	250	6740	22/8	0.27	0.49	31.0	0.030	1.16	
	300	6770	24/8	0.29	0.53	28.9	0.033	1.16	

CONSTRAINT: M ≤ 0.55
T/W ≤ 0.26

KWIND = 0.35

STRUCTURE	2832025
FUSELAGE	1151573
WING	967750
HORIZ TAIL	192814
VERT TAIL	101496
LANDING GEAR	125673
ENGINE SEC	292716
PROPULSION	713670
ENGINES	455239
OTHER PROPULS	258430
FIXED EQUIPMENT	212300
FLIGHT CONTR	55323
HYDRAULIC SYS	46702
ELECTRICAL	34231
AVIONICS, IN	4000
INSTRUMENTATN	4905
FURNISHINGS	52611
AUX POWER	1600
AIR COND	6105
ANTI-ICING	2820
LOAD & HANDL	4000
CONTY	0
WEIGHT EMPTY	3757996
OPER WEIGHTS	51445
OPER WT EMPTY	3809442
PAYLOAD	2000000
FUEL	4190558
GROSS WEIGHT	1E+07

GW	FRACPL	RANGE	ARW	LOADWING
1E+07	.2	6683.461	3	250
TIME	MINITCR	FRACFUEL*100	WE/GW	NENG
22.18867	.5418115	41.90558	.3757997	18
NENGOP	T/W	L/D	HPAR	(H/B WIG)*100
8	.2322203	25.82465	10.0608	3.464102
TREQPAR	KMATL	HWIG	IBURN	ENGSCL
2322203	.8	12	1	1.24
TSFCIC	SFCVEHIC	W	H	L
.5540118	.5722833	32.50222	51.42475	468.682
TCR	TCT	WWING	STRUCT	THETA
.1	.1	967750.5	2832026	2.049

Figure C-11. Wingship Group Weight Statement

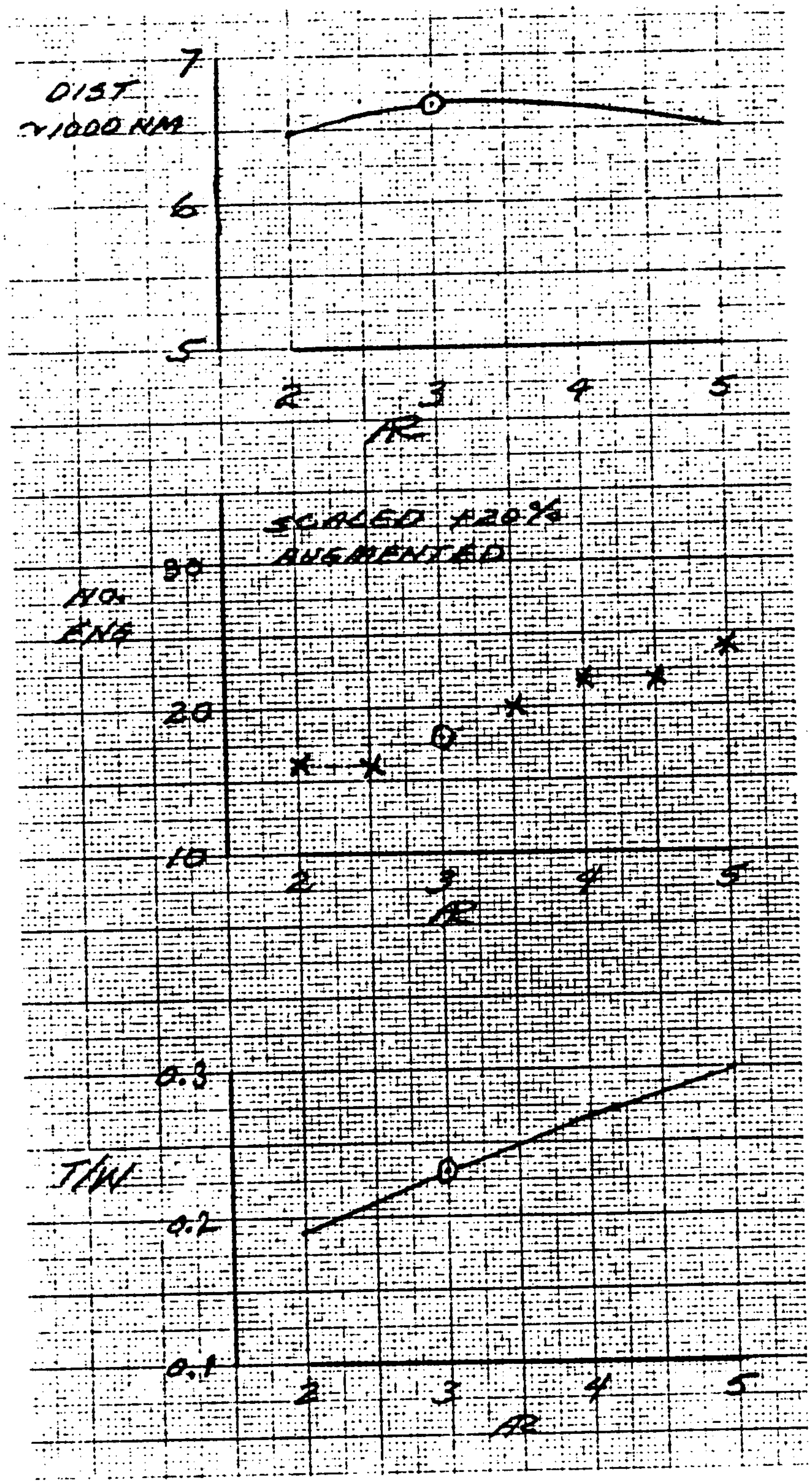


Figure C-12. Sensitivities: Wing Aspect Ratio

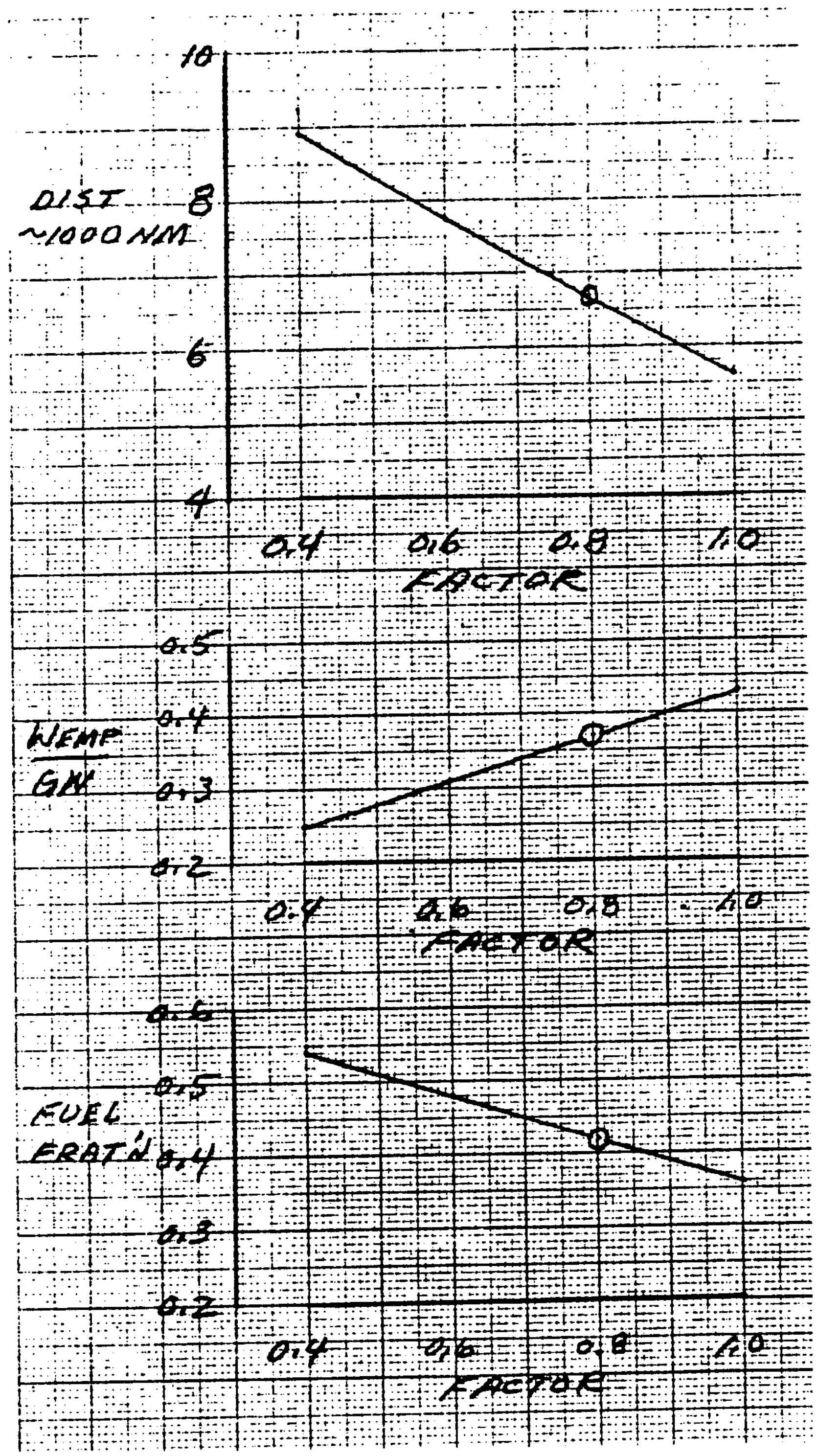


Figure C-13. Sensitivities: Structural Materials Weight Factor

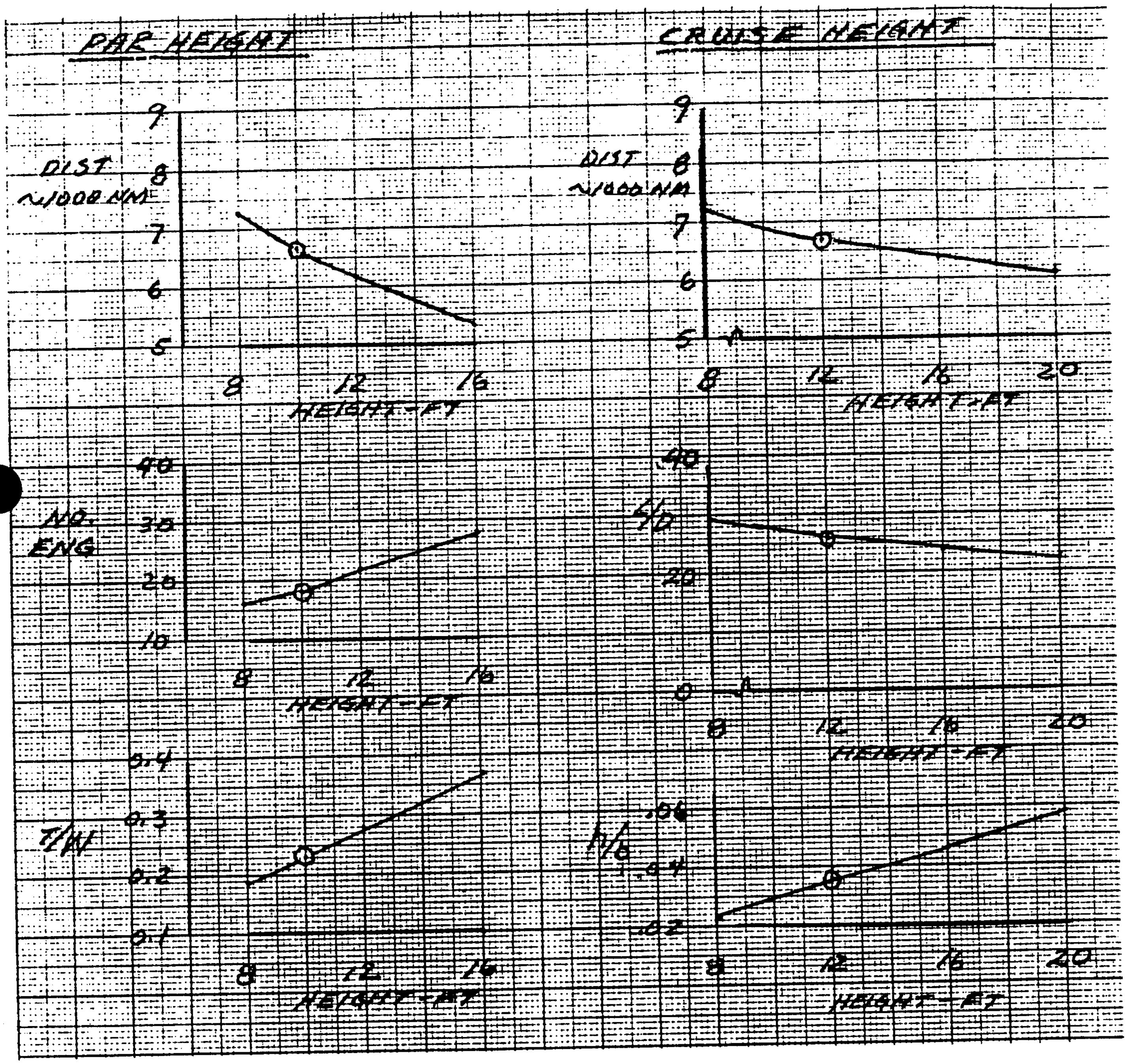


Figure C-14. Sensitivities: Operating Weight

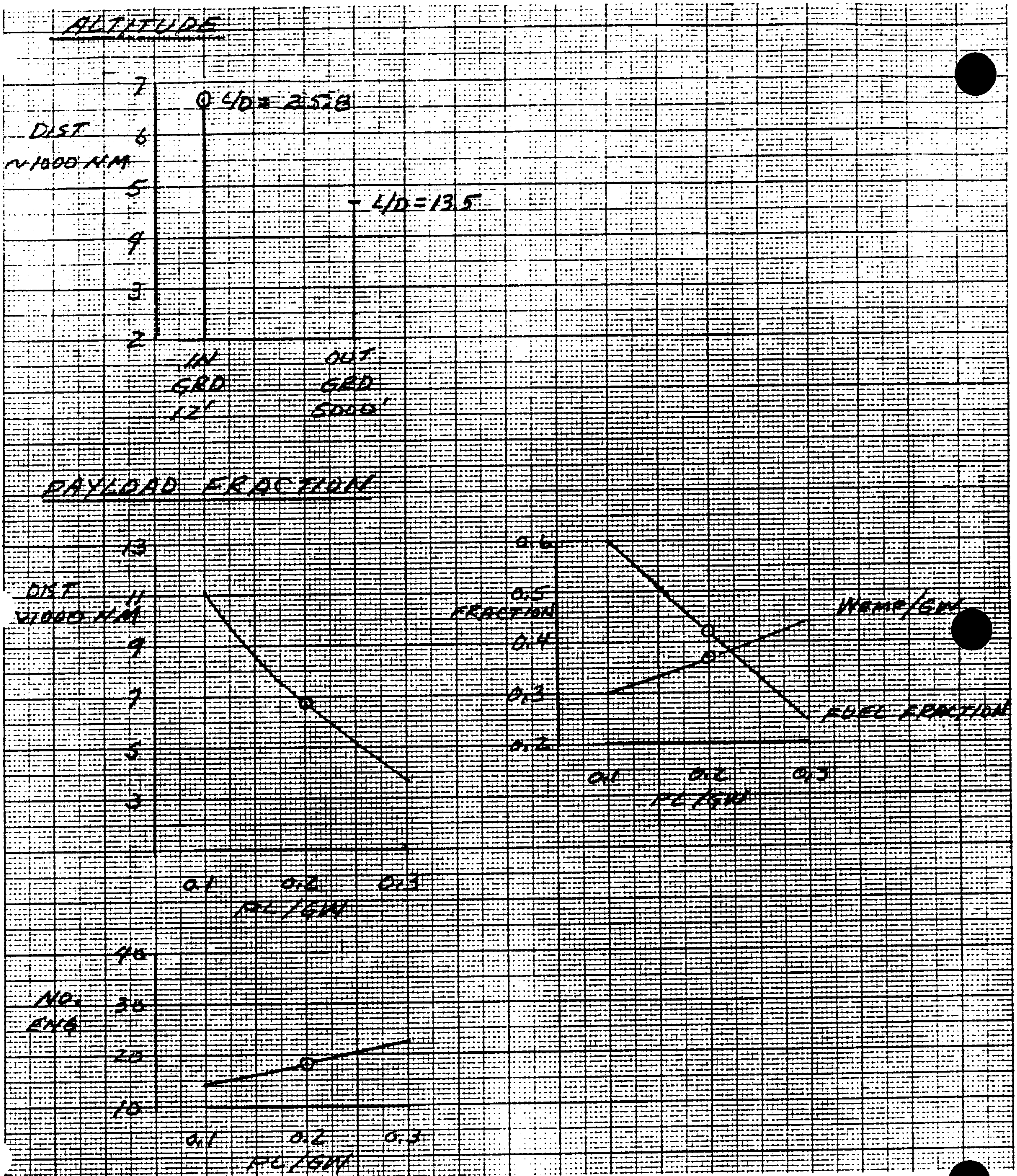


Figure C-15. Sensitivities: Altitude/Payload Fraction

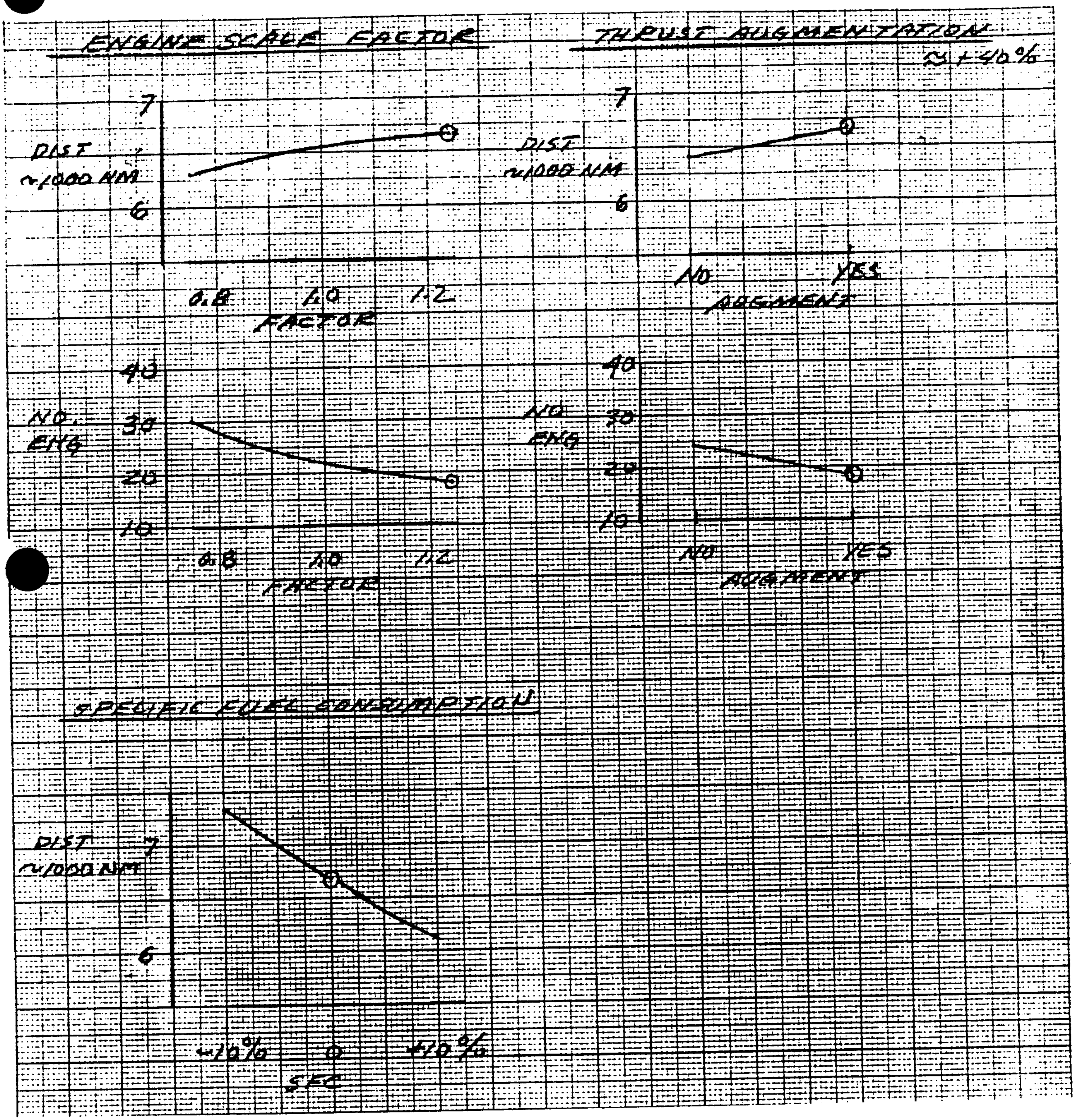


Figure C-16. Sensitivities: Engine Performance Parameters

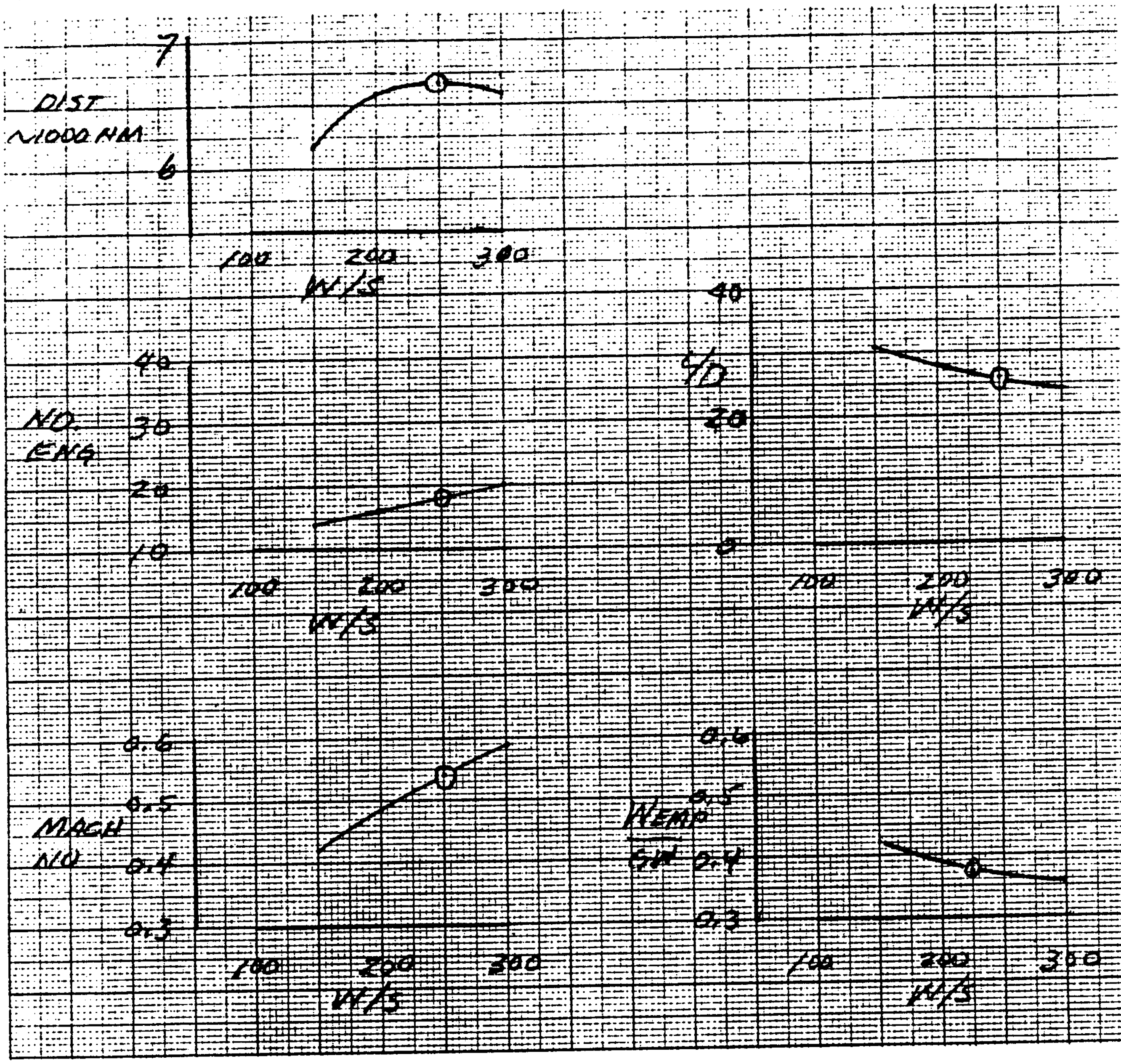


Figure C-17. Sensitivities: Wing Loading

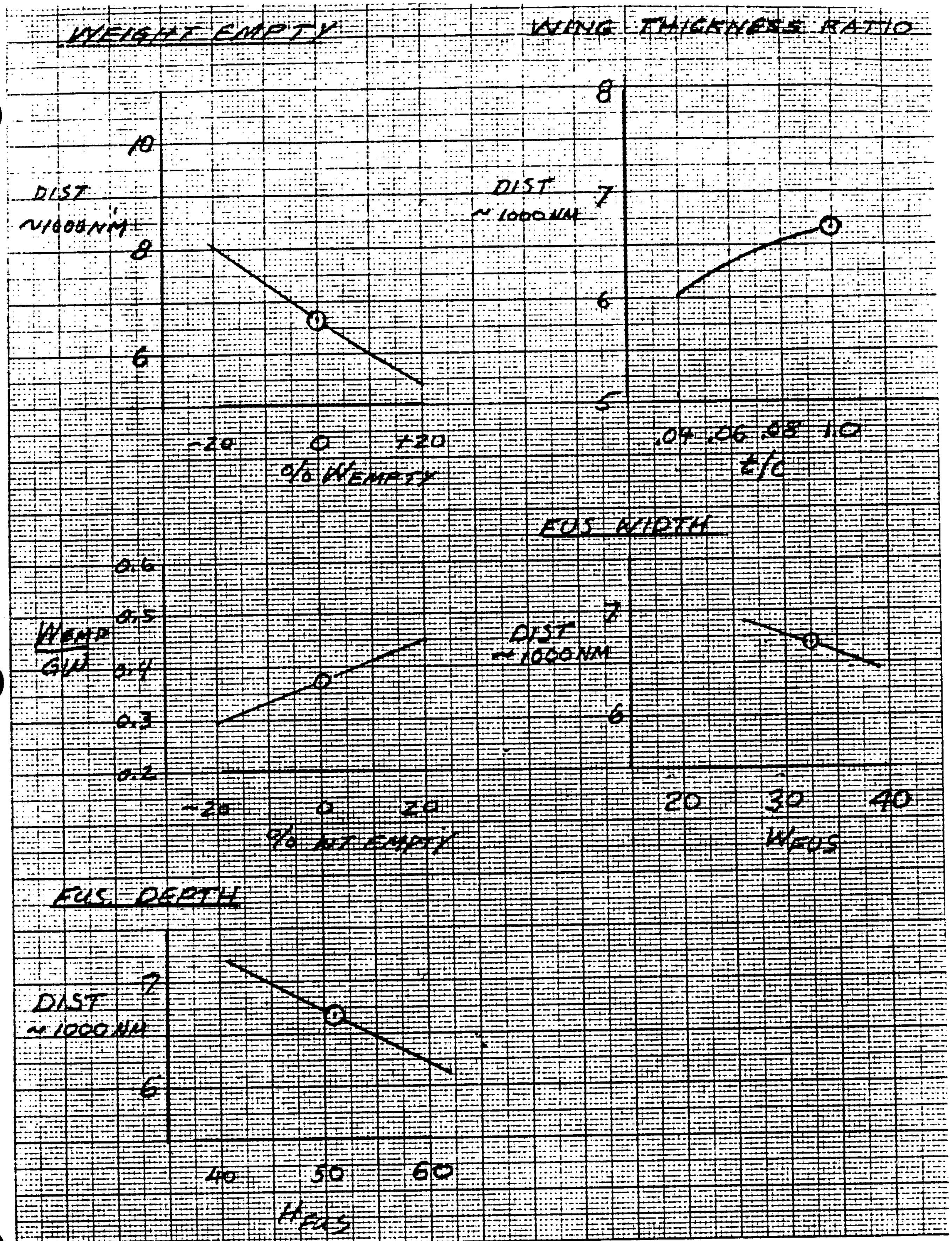


Figure C-18. Sensitivities: Weight Empty/Wing Thickness Ratio/Fus. Width-Depth

Landplane and Seaplane Performance

CONTENTS

Appendix D

LANDPLANE CAPABILITY

As part of this study, data on landplanes and future landplane concepts was acquired from various sources. The primary categories of aircraft considered were bombers for their potential long range capability, unrefuelled, and transport aircraft both commercial and military. Only domestic bombers were considered and only recently unclassified data was used. This limited consideration to these bombers arranged by increasing Maximum Take-Off Weight (MTOW - lbs), shown hereunder in Table 1:

TABLE 1

Aircraft	# of Engines	MTOW	Reference
Convair B-58A	4	163,000	1
Rockwell B-1A	4	389,800	2
Boeing B-52G	8	488,000	3

Although the B-58A and B-1A were designed to be able to dash cruise at supersonic speed, the greater portions of their primary missions were to be conducted at subsonic speeds. The bombers also exhibited lower empty weight fractions relative to commercial aircraft. In some part this was due to construction methods and materials and, also, the lower load factors used by the service for their operation.

Data on large landplanes and future landplane concepts other than the bomber data identified above was acquired from various sources identified in Table 2. Reference 4 is "Janes All The World Aircraft" and numerous editions were used to gather data because data on a particular aircraft type varied from one volume to another or there was inadequate data in one volume and it had to be supplemented by data from another volume. Therefore, the year span for this data is identified in the references for all aircraft rather than a particular aircraft.

TABLE 2

Aircraft	# of Engines	MTOW	Reference
Airbus 321-100	2	181,220	4
Boeing 727-200	3	209,501	4
Boeing 757-200	2	240,965	4
Boeing 707-320B	4	333,690	4
Vickers Super VC-10	4	335,000	4
Douglas DC-8 Srs 63	4	350,000	4
Airbus A300-600R	2	380,520	4
Boeing 767-300ER	2	400,000	4
Lockheed L-1011-1 Tristar	3	430,000	4
McDonnell Douglas DC-10 Series 10	3	455,000	4
Lockheed L-1011-200 Tristar	3	466,000	4
Airbus 330-300	2	491,030	4
Lockheed L-1011-500 Tristar	3	504,000	4
McDonnell Douglas DC-10 Series 30	3	572,000	4

civilian aircraft empty weights compatible with the military empty weights the civilian Basic Operating Weight or Operating Weight Empty was reduced by 0.03% to allow for unusable fuel and oil, crew and crew baggage, water, food and other miscellaneous items of convenience not in the basic payload. The Dr. L. M. Nikolai line is the result of a regression derived equation presented in his Course on Aircraft Design of 16 July, 1984. The equation is:

$$W_{(Empty)} = 0.911*(MTOW)**0.947$$

It is clearly a good predictor of empty weight for landplanes. Note that the Super VC-10 had an empty weight fraction 0.443 which was at least 10% higher than its competition. These higher fraction was caused by the requirement to operate from hot and high runways with no payload degradation and the positioning of the engines on the rear of the fuselage aft of the wing trailing edge, two either side in siamese nacelles. This arrangement is similar to the Lun/Spasatel. But they have four engines each side of the fuselage in a common nacelle pod ahead of the wing.

Figure 4 shows useful load to gross weight ratio which is directly related to the empty weight fraction and can be used for gaging the payload and range capability. Useful load is the summation of fuel and payload.

Figure 5 shows the projected fuel weight to gross weight ratio for landplanes. Although the trend line tends to show a decreasing fuel weight/gross weight fraction, the gradient of which might be steeper with the introduction of new structural materials, the majority of points indicate that it will tend to remain constant. The bombers show a significant increase due to the lower payload fraction and lower operational load factors (g's) than commercial aircraft.

Figure 6 and 7 show the maximum payload and payload with maximum fuel to weight ratio versus gross weight, respectively. The trends clearly show an increase in payload for a given range with increase in aircraft gross weight. As can be seen, with very large landplanes payload fractions of 10 - 15% are likely with passenger payload. With maximum payload no aircraft can currently achieve a range in excess of 7,000 n.m., Figure 8. Figure 9, shows ranges above 7,000 nautical miles can be achieved with maximum fuel load with a gross weight of the order of 266 metric tons. Note that the Super VC-10 which had a MTOW of 335,000lb had considerably less range than the Boeing 707-320B. This was caused by three design features:

- o hot and high airfield capability
- o increased structural weight due to the rear location of the Rolls Royce RCO-43 Conways
- o increased drag associated with mounting two engines side by side (Siamese Nacelles) on each side of the fuselage.

TABLE 2 (Cont'd)

Aircraft	# of Engines	MTOW	Reference
McDonnell Douglas C-17	4	580,000	4
Airbus A340-300	4	588,630	4
Boeing 777 B2	2	590,000	4
McDonnell Douglas MD-11	3	618,000	4
Boeing 747SP	4	700,000	4
Boeing 747-100	4	710,000	4
Boeing 747-200	4	833,000	4
Boeing 747-300	4	833,000	4
Lockheed C-5B	4	837,000	4
Boeing 747-400	4	870,000	4
McDonnell Douglas MD-12	4	949,000	4
Lockheed SpanLoader	6	1,200,000	5
Dornier 1000 Concept	10	2,205,000	6

Commercial aircraft considered included two, three and four engine aircraft either in or about to enter service, a large long range high capacity aircraft project, a spanloader and a landplane /seaplane concept of the early 1980's. Data on Soviet large commercial and military transports is sketchy and was inadequate to include in the current data base. Specific aircraft and projects considered are arranged by increasing Maximum Take-Off Weight (MTOW - lbs) as shown above.

Figure 1 shows the thrust to weight ratio as a function of gross weight. The bombers, specifically the B-58 and B-1A were supersonic and this was reflected in their thrust to weight ratios. The Boeing 727-200 has a higher thrust to weight ratio than the current long range first generation jets owing to the airline requirements to be able to use medium length runaways, 6,000 to 7,000 ft. The higher thrust to weight ratio of the Super VC-10 also is a result of airfield requirements. Because of the thrust lapse rate of the large high bypass ratio turbofans with both altitude and speed, it was necessary to use a higher thrust to weight ratio to obtain the cruise speeds and altitudes of the medium to long range narrow body jets. The twin engine jets are penalized to some extent because of the single engine second segment climb and possible single engine cruise altitude requirements. This results in a higher thrust to weight ratio than the three and four engined airliners. However, a side benefit of the certification requirements are shorter runway lengths for take-off.

Figure 2 shows the wing loading plotted as a function of gross weight. As can be seen the general trend for subsonic aircraft is to go to higher wing loadings while the reverse is true for large supersonic aircraft. To offset span limitations the use of lower aspect ratio wings and loadings is predictable for future ultra large landplanes.

Figure 3 shows the empty weight to gross weight ratio for the selected landplanes. The general trend is towards decreasing empty weights as gross weight is increased. In order to make the

An intangible benefit of the Super VC-10 configuration which is not shared by the Russian Lun/Spasatel configuration since the engines are ahead of the wing leading edge, was that the passenger cabin was the quietest of any airliner. Once airborne the noise of the Rolls Royce Conways was never heard. U.K. Civil Aviation Authority did not allow passengers to sit in line with the engine compressor faces. BOAC experienced much higher load factors on routes flown by the Super VC-10 and VC-10's compared to when using the 707-420. The low bypass Conway engines caused a minor sonic fatigue problem with the horizontal stabilizer resulting in a beef-up of the skin and stabilizer trim hinges. A sonic fatigue problem may not occur on the Lun/Spasatel because the fuselage and wing skins are much heavier for other reasons. However, sound proofing is likely to be a necessity given the location of the engines. In short, the British experience with the VC-10 suggests that even a reversed configuration as with the Lun/Spasatel is likely to be a relatively poor performer as a flying machine excluding all other aspects of its design.

Figure 10, shows the cruise speed trend as a function of gross weight. Although Mach number effects can be expected to limit cruise Mach number, if landplanes get larger decreases in parasitic drag coefficient may be offset by higher induced drag owing to terminal constraints limiting the span of future large landplanes. However, new wings designed to achieve laminar flow may result in slightly higher cruise speeds. Whether a net gain results will be dependent on the engine specific fuel consumption characteristics.

References

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2. B-1A, Standard Aircraft Characteristics, Unclassified, AFG 2, Vol-1, Addn 59, December 1986

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4. "Janes All The World Aircraft", Editions 1965 thru 1993, Janes Data Division, Janes Information Group Limited, Sentinel House, 163 Brighton Road, Coulsdon, Surrey CR5 2NH, U.K.

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LANDPLANES
Thrust to Weight Ratio

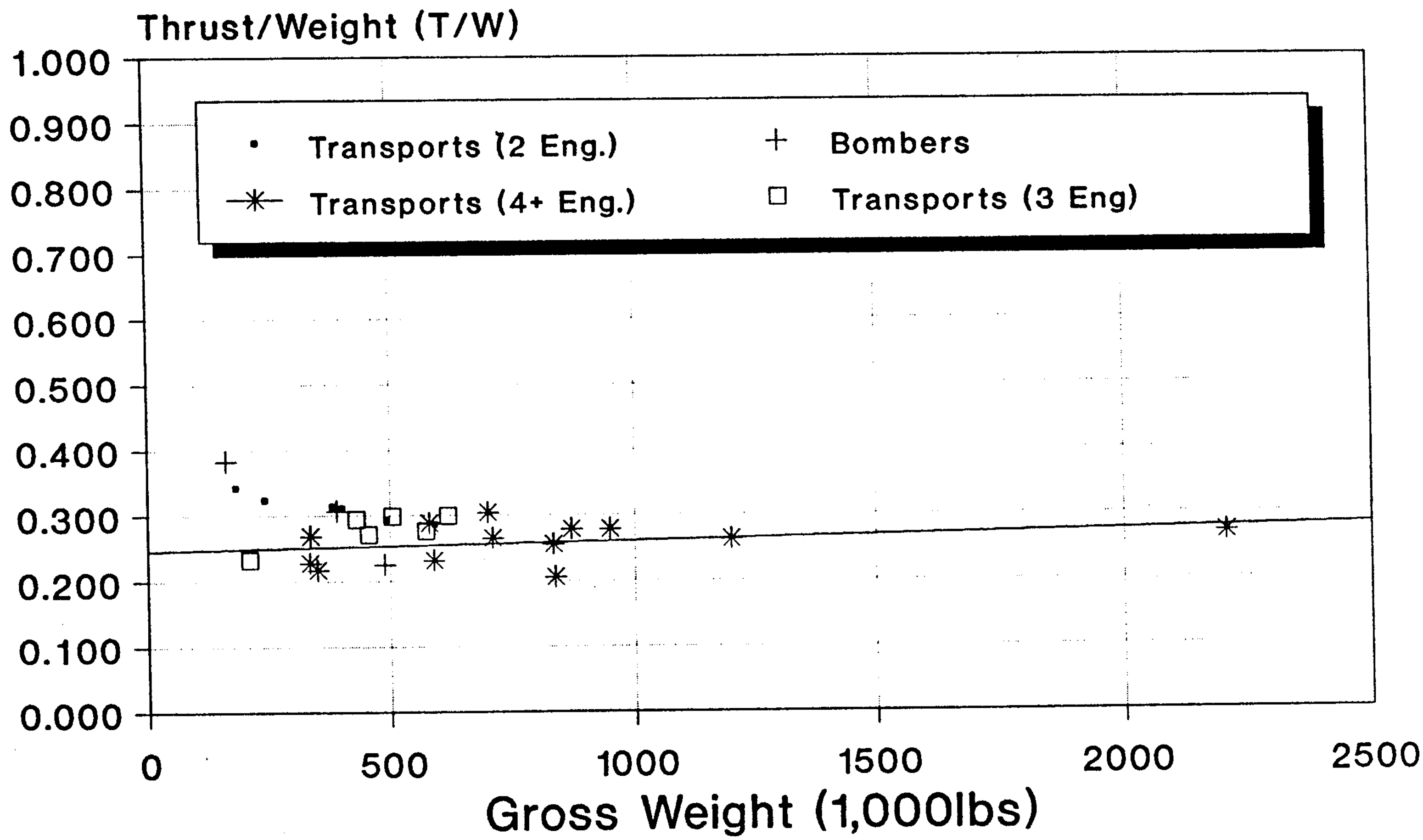


FIGURE 1

LANDPLANES

Wing Loading vs Gross Weight

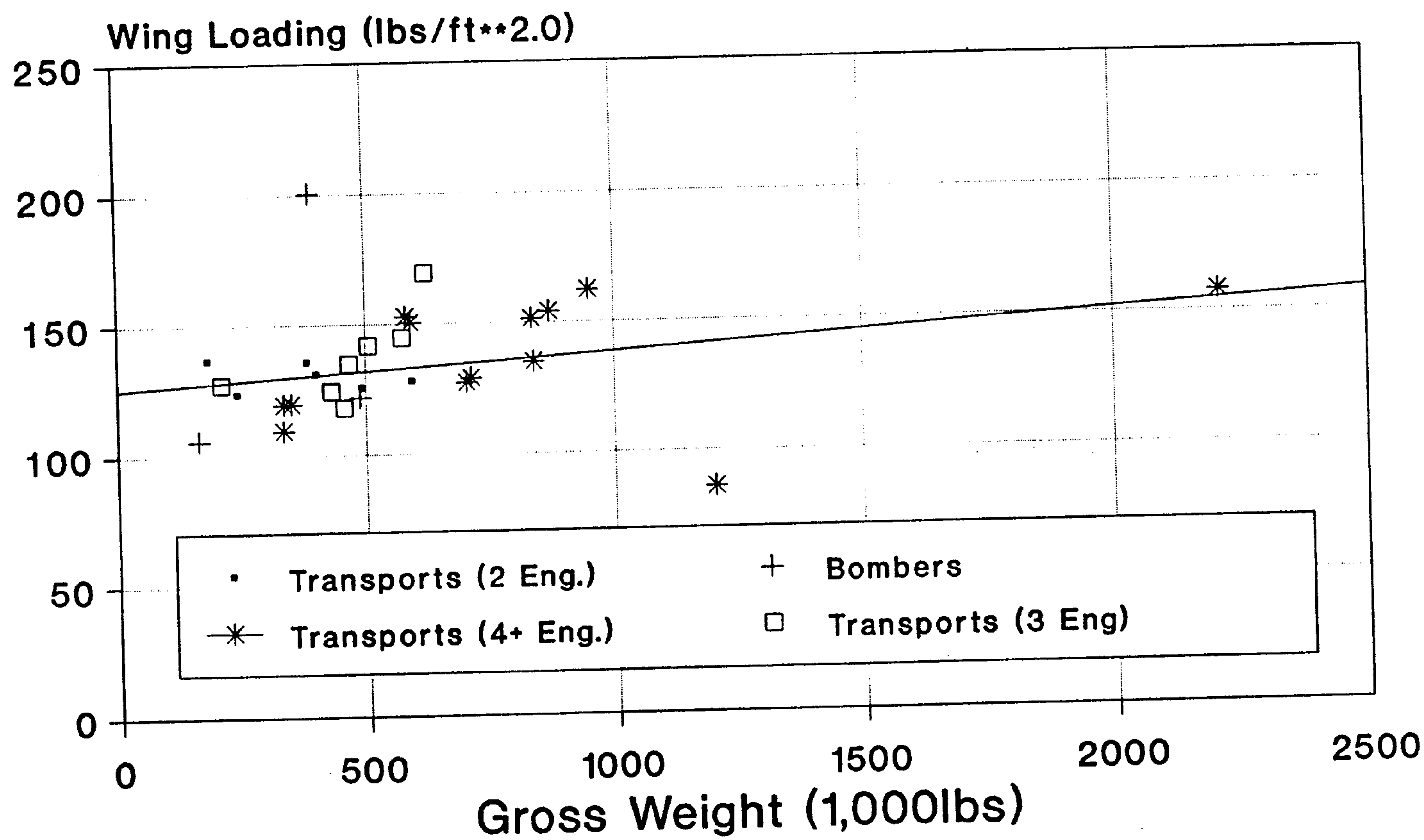
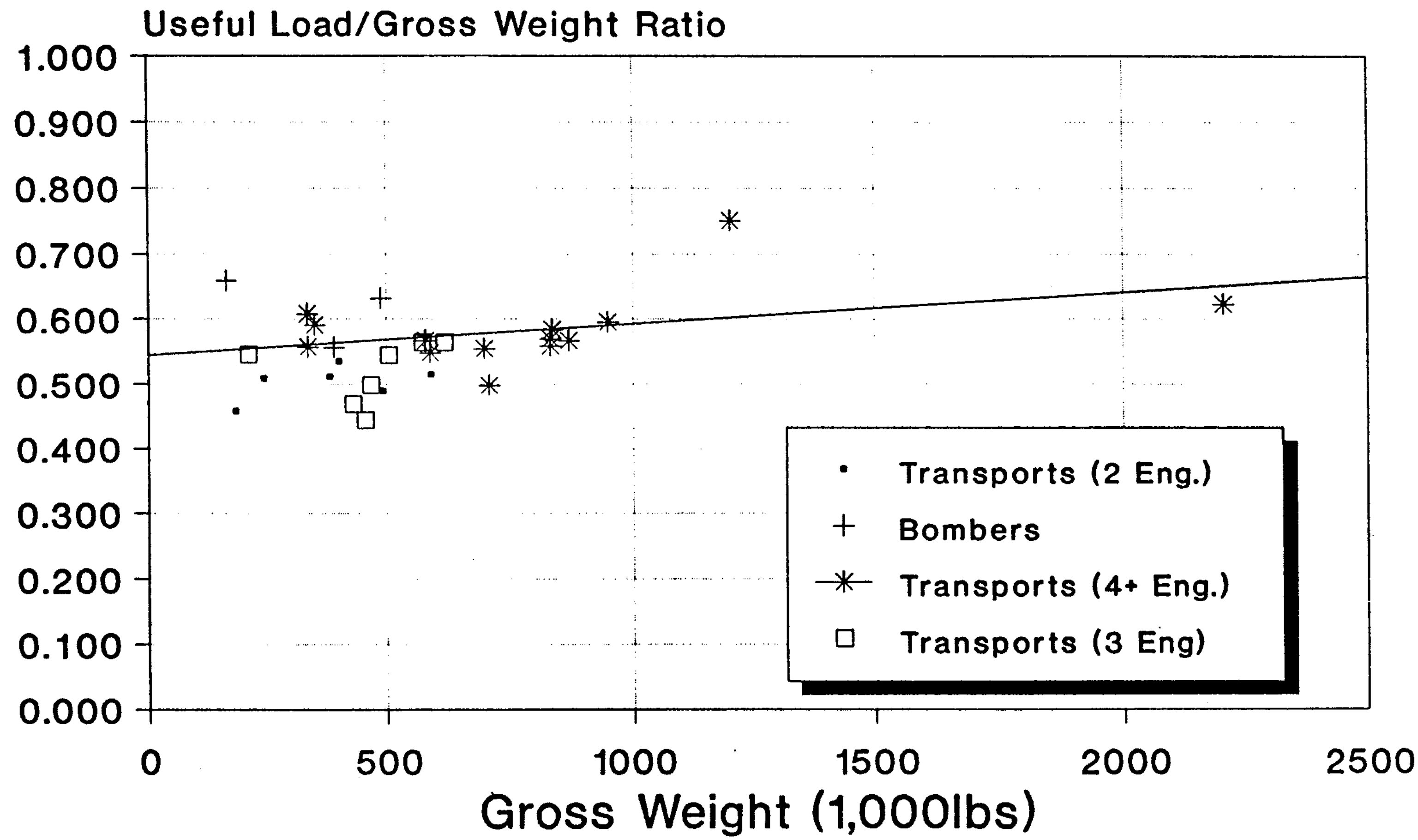


FIGURE 2

LANDPLANES

Useful Load to Gross Weight Ratio

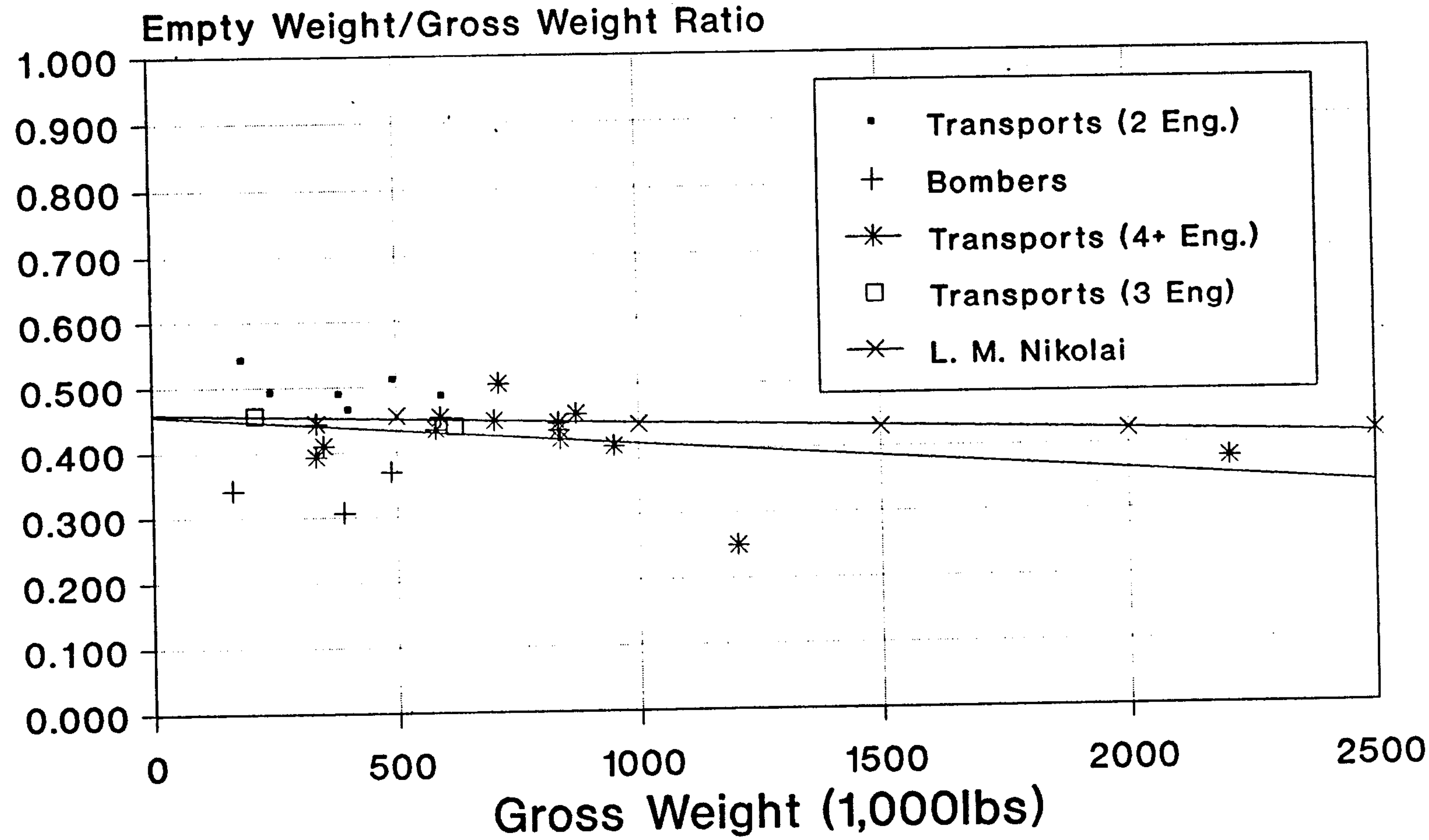


Gross Weight = M.T.O.W.

FIGURE 4

LANDPLANES

Empty Weight to Gross Weight Ratio

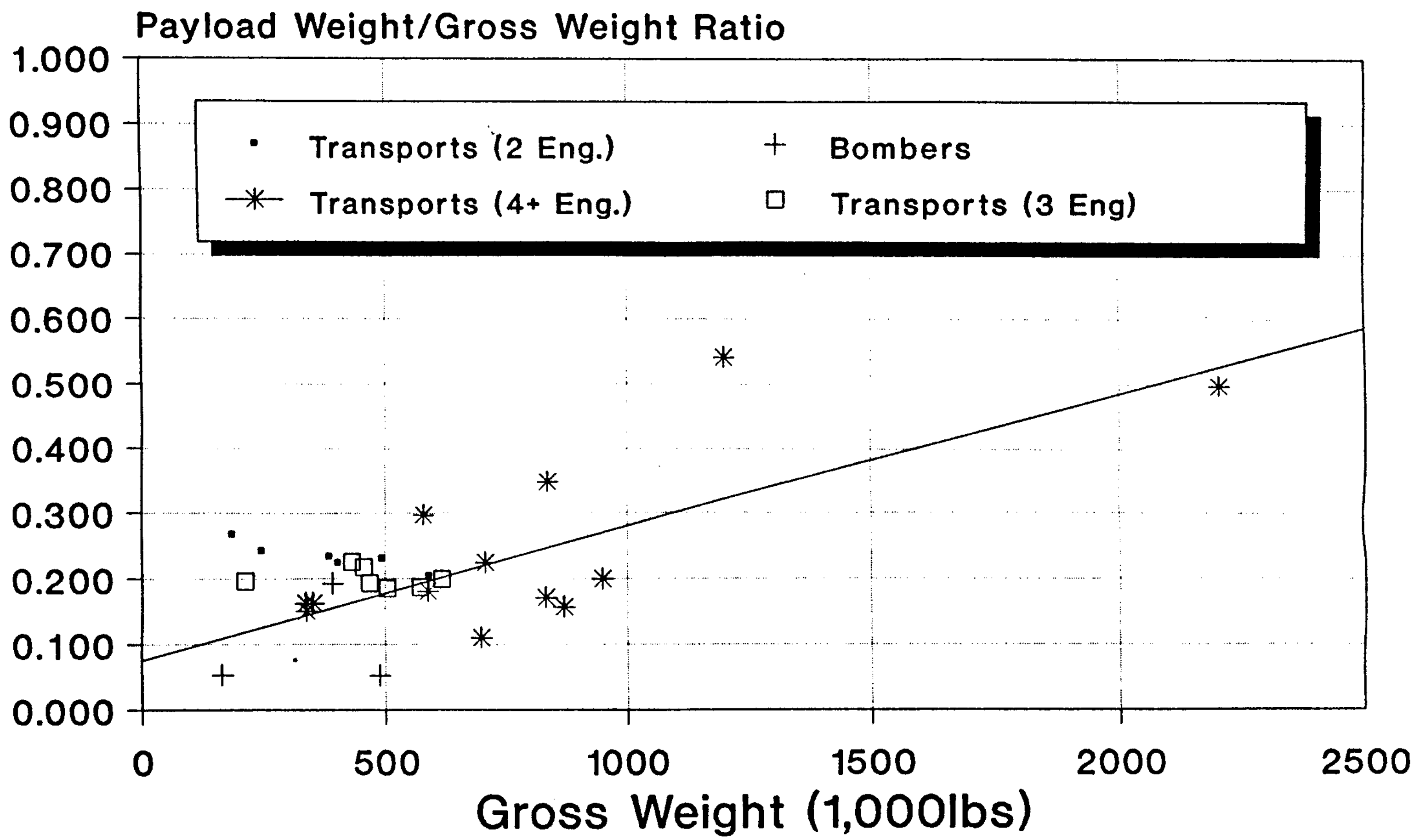


Gross Weight = M.T.O.W.

FIGURE 3

LANDPLANES

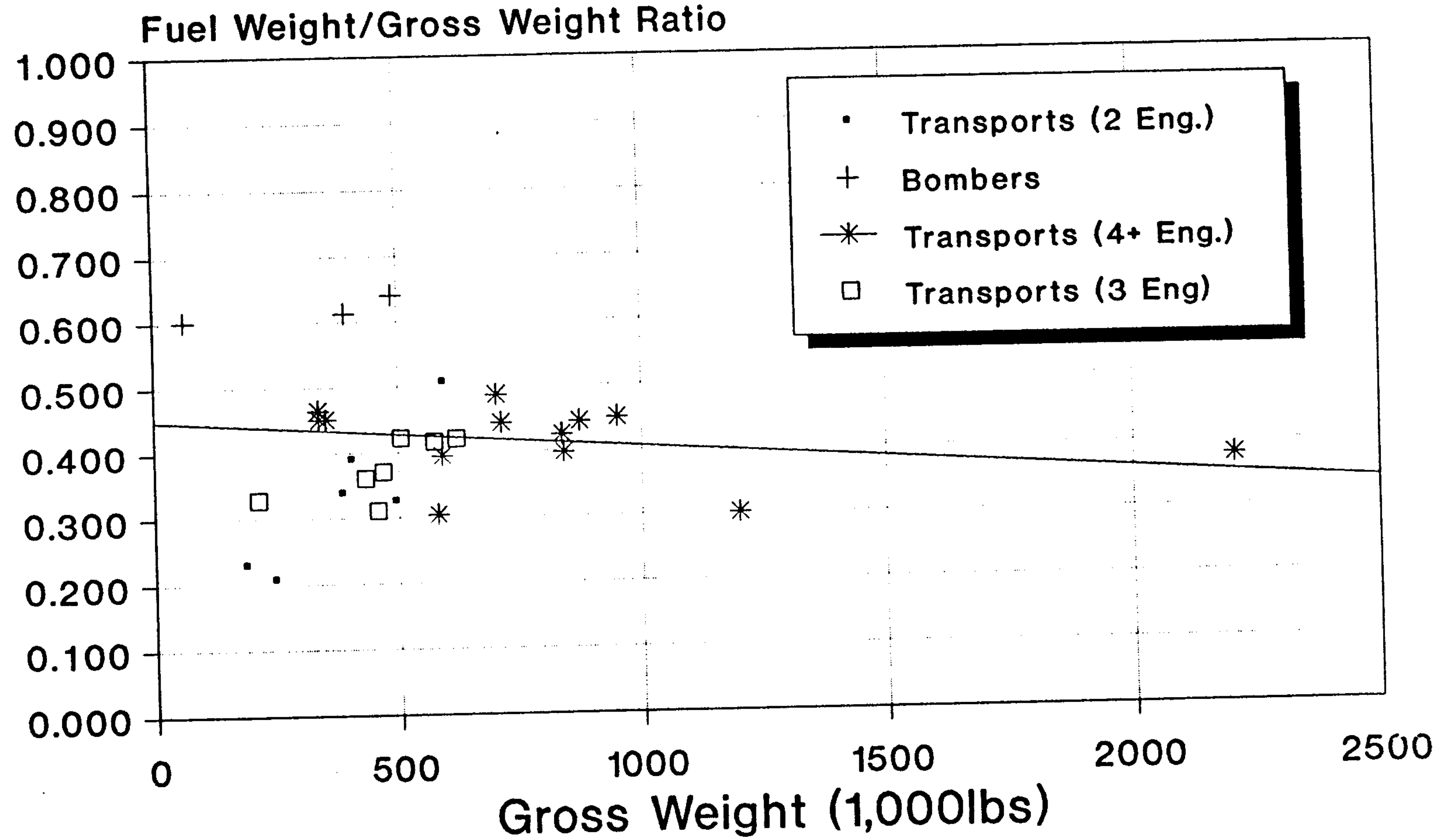
Payload* Weight to Gross Weight Ratio



*Note: Maximum Payload

LANDPLANES

Fuel Weight to Gross Weight Ratio

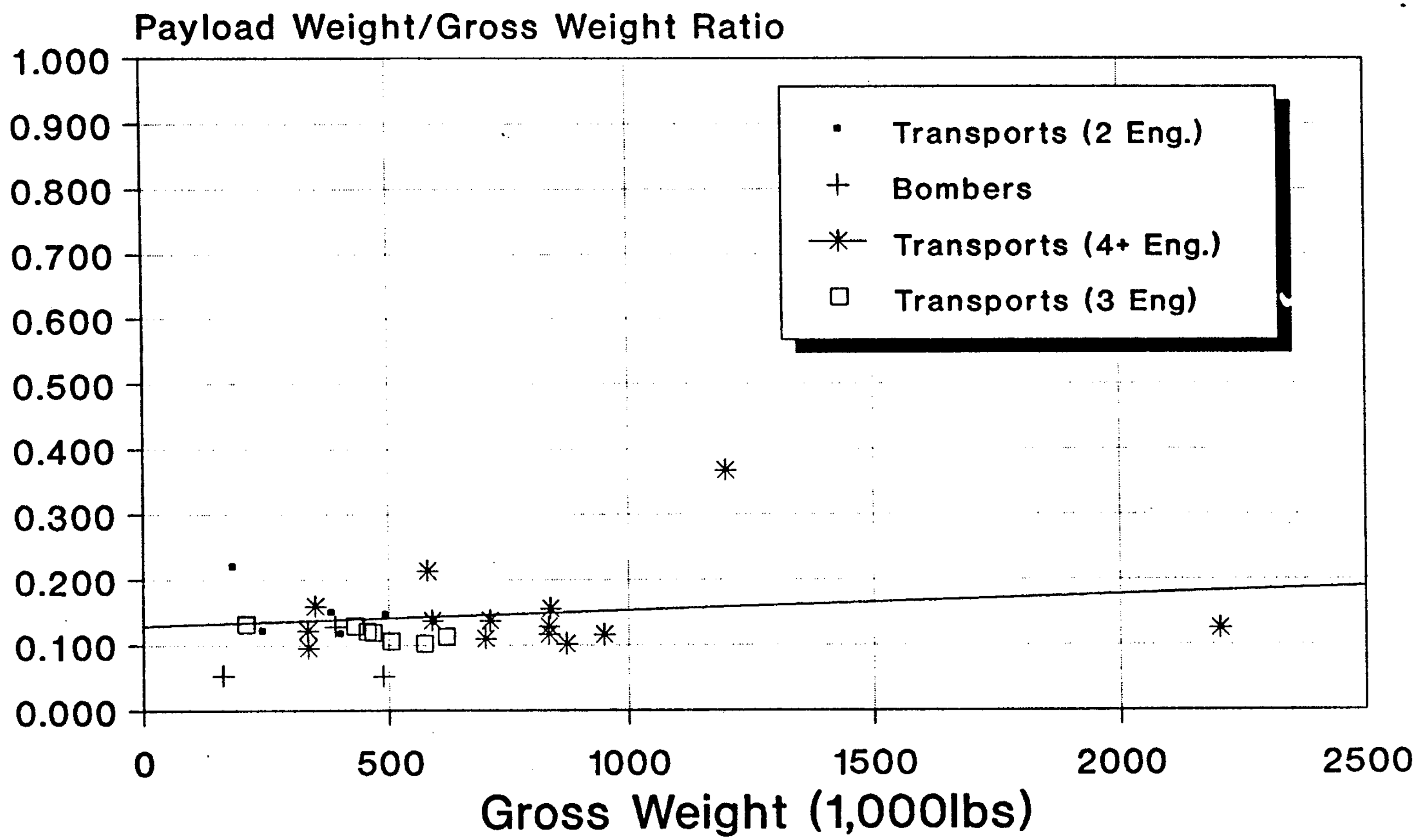


Gross Weight = M.T.O.W.

FIGURE 5

LANDPLANES

Payload* Weight to Gross Weight Ratio



*Note: Payload with Maximum Fuel

Figure 7

LANDPLANES

Range @ Max Payload

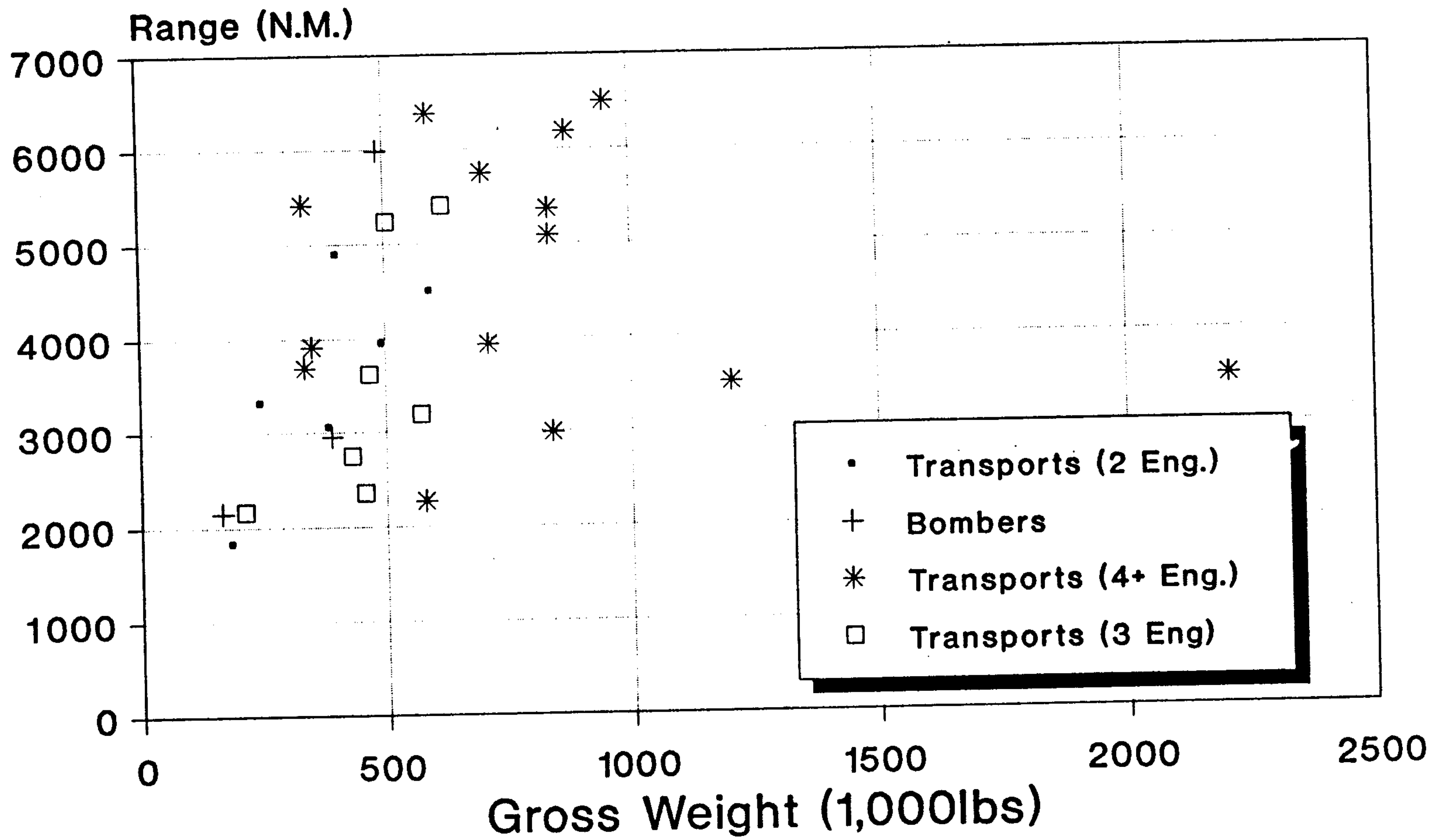


FIGURE 8

LANDPLANES
Range with Max. Fuel

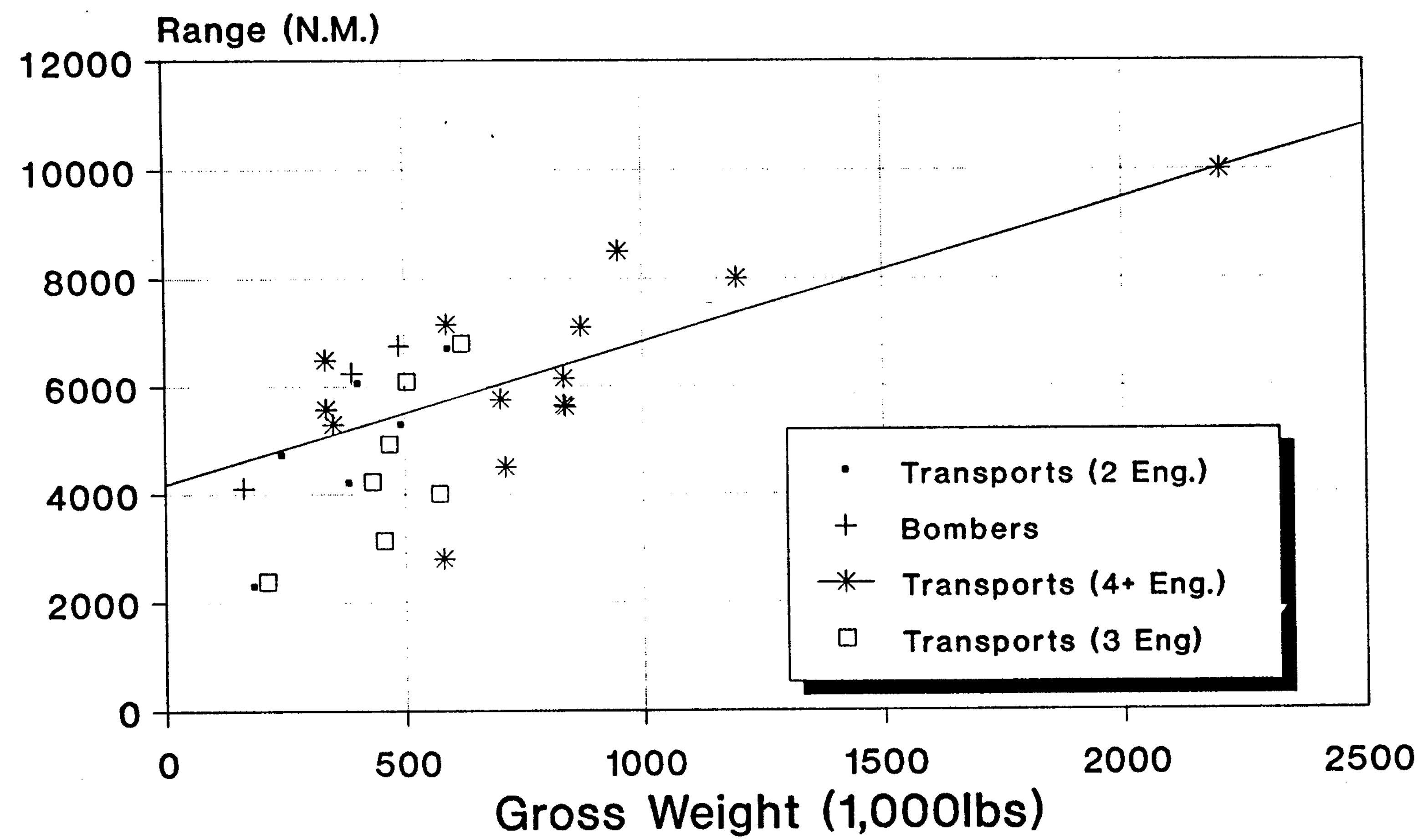


FIGURE 9

LANDPLANES

Cruise Speed vs Gross Weight

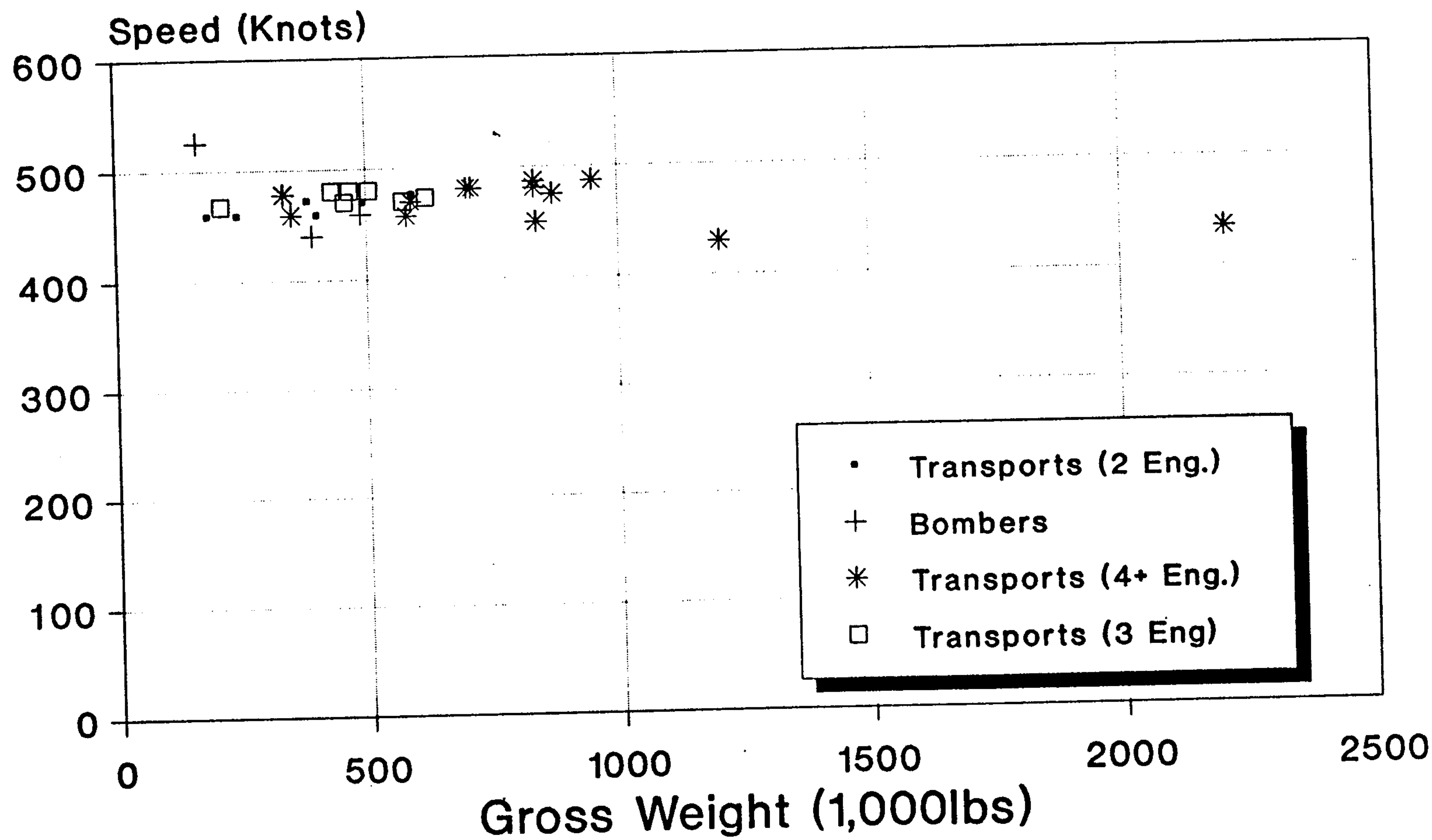


FIGURE 10

Parameter	Convair Hustler B-58	North American B-1A	Boeing B-52G	Airbus A321-100
Gross Weight (lbs)	163,000.00000	389,800.00000	488,000.00000	181,220.00000
Thrust, Total (lbs)	62,400.00000	119,400.00000	110,000.00000	62,000.00000
Empty Weight (lbs)	55,600.00000	173,000.00000	180,041.00000	103,771.00000
Payload (lbs)	8,555.00000	50,000.00000	25,469.00000	39,990.00000
Range (n.m.); Max Fuel	4,100.00000	6,242.00000	6,758.00000	2,300.00000
Range @ Max Payload (n.m.)	2,145.00000	2,954.00000	5,986.00000	1,831.00000
Maximum Payload (lbs)	8,555.00000	75,000.00000	25,469.00000	48,546.00000
Cruise Speed (knots)	525.00000	562.00000	459.00000	459.00000
Gross Wing Area (ft**2.0)	1,542.50000	1,946.00000	4,000.00000	1,325.00000
Wing Loading (lbs/ft**2)	105.67261	200.30832	122.00000	136.76981
Max Fuel Weight (lbs)	98,020.00000	238,687.00000	312,195.00000	41,943.00000
Thrust/Gross Weight	0.38282	0.30631	0.22541	0.34213
Empty Weight/Gross Weight	0.34110	0.44382	0.36894	0.54262
Fuel Weight/Gross Weight	0.60135	0.61233	0.63974	0.23145
Maximum Payload/Gross Weight	0.05248	0.19241	0.05219	0.26788
Useful Load/Gross Weight	0.65890	0.55618	0.63106	0.45738
Payload/Gross Weight with Maximum Fuel	0.05248	0.12827	0.05219	0.22067

Boeing -200	Boeing 757-200	Boeing 707-320	Vickers Super VC-10	Douglas DC-8 Series 63	Airbus A300-600R
209,501.00000	240,965.00000	333,690.00000	335,000.00000	350,000.00000	380,520.00000
48,559.00000	76,435.00000	76,000.00000	90,000.00000	76,000.00000	123,000.00000
101,774.00000	125,811.00000	141,000.00000	158,594.00000	153,749.00000	197,523.00000
27,500.00000	38,449.00000	40,635.00000	32,000.00000	55,685.00000	57,405.00000
2,370.00000	4,727.00000	6,493.00000	5,571.00000	5,300.00000	4,210.00000
2,160.00000	3,319.00000	5,420.00000	3,689.00000	3,907.00000	3,060.00000
40,993.00000	58,489.00000	53,900.00000	50,406.00000	67,735.00000	89,077.00000
467.00000	459.00000	478.00000	478.00000	459.00000	472.00000
1,647.00000	1,948.00000	3,050.00000	2,806.00000	2,927.00000	2,799.00000
127.20158	123.69867	109.40656	119.38703	119.57636	135.94855
68,705.00000	50,385.00000	155,058.00000	151,047.00000	157,788.00000	129,230.00000
0.23178	0.31720	0.22776	0.26866	0.21714	0.32324
0.45579	0.49211	0.39255	0.44341	0.40928	0.48909
0.32795	0.20910	0.46468	0.45089	0.45082	0.33961
0.19567	0.24273	0.16153	0.15047	0.19353	0.23409
0.54421	0.50789	0.60745	0.55659	0.59072	0.51091
0.13126	0.15956	0.12177	0.09552	0.15910	0.15086

Boeing '67-300ER	Lockheed L-1011-1 Tristar	McDonnell Douglas DC-10 Series 10	Lockheed L-1011-200 Tristar	Airbus A330-300	Lockheed L-1011-500 Tristar
400,000.00000	430,000.00000	455,000.00000	466,000.00000	491,030.00000	504,000.00000
124,364.00000	126,000.00000	123,000.00000	144,000.00000	144,000.00000	150,000.00000
198,195.00000	241,700.00000	267,197.00000	248,400.00000	266,020.00000	245,400.00000
46,892.00000	55,040.00000	54,825.00000	55,040.00000	72,025.00000	52,890.00000
6,060.00000	4,220.00000	3,125.00000	4,920.00000	5,300.00000	6,080.00000
4,897.00000	2,740.00000	2,350.00000	3,610.00000	3,947.00000	5,236.00000
89,794.00000	83,300.00000	98,500.00000	89,600.00000	113,000.00000	92,608.00000
459.00000	480.00000	470.00000	480.00000	470.00000	480.00000
3,050.00000	3,456.00000	3,861.00000	3,456.00000	3,908.00000	3,556.00000
131.14754	124.42130	117.84512	134.83796	125.64739	141.73228
156,325.00000	154,791.00000	141,050.00000	172,263.00000	160,550.00000	212,000.00000
0.31091	0.29302	0.27033	0.30901	0.29326	0.29762
0.46549	0.53209	0.55725	0.50305	0.51176	0.45690
0.39081	0.35998	0.31000	0.36966	0.32697	0.42063
0.22448	0.19372	0.21648	0.19227	0.23013	0.18375
0.53451	0.46791	0.44275	0.49695	0.48824	0.54310
0.11723	0.12800	0.12049	0.11811	0.14668	0.10494

McDonnell Douglas Series 30	McDonnell Douglas C-17	Airbus A340-300	Boeing 777 B2	McDonnell Douglas MD-11	Boeing 747SP
572,000.00000	580,000.00000	588,630.00000	590,000.00000	618,000.00000	700,000.00000
157,500.00000	166,800.00000	136,000.00000	168,800.00000	184,500.00000	212,440.00000
267,197.00000	269,000.00000	283,750.00000	304,500.00000	288,880.00000	333,000.00000
58,050.00000	124,000.00000	80,625.00000	80,625.00000	69,445.00000	77,000.00000
4,000.00000	2,800.00000	7,150.00000	6,700.00000	6,791.00000	5,750.00000
3,182.00000	2,262.00000	6,379.00000	4,500.00000	5,402.00000	5,750.00000
106,550.00000	172,000.00000	106,460.00000	120,500.00000	122,700.00000	77,000.00000
470.00000	457.00000	470.00000	476.00000	473.00000	481.00000
3,958.00000	3,800.00000	3,908.00000	4,605.00000	3,648.00000	5,500.00000
144.51743	152.63158	150.62180	128.12161	169.40789	127.27273
237,250.00000	176,202.00000	231,816.00000	299,490.00000	259,100.00000	339,920.00000
0.27535	0.28759	0.23104	0.28610	0.29854	0.30349
0.43713	0.43379	0.45205	0.48610	0.43744	0.44571
0.41477	0.30380	0.39382	0.50761	0.41926	0.48560
0.18628	0.29655	0.18086	0.20424	0.19854	0.11000
0.56287	0.56621	0.54795	0.51390	0.56256	0.55429
0.10149	0.21379	0.13697	0.13665	0.11237	0.11000

Boeing 747-100B	Boeing 747-200B	Boeing 747-300	Lockheed C-5B	Boeing 747-400	McDonnell Douglas MD-12
710,000.00000	833,000.00000	833,000.00000	837,000.00000	870,000.00000	949,000.00000
187,800.00000	212,440.00000	212,440.00000	172,000.00000	242,400.00000	256,000.00000
378,000.00000	384,000.00000	393,000.00000	374,000.00000	402,900.00000	413,000.00000
97,180.00000	97,180.00000	106,640.00000	130,500.00000	88,580.00000	109,865.00000
4,500.00000	6,150.00000	5,650.00000	5,618.00000	7,100.00000	8,000.00000
3,928.00000	5,362.00000	5,085.00000	2,982.00000	6,182.00000	6,498.00000
148,500.00000	142,500.00000	142,000.00000	291,000.00000	136,549.00000	189,000.00000
481.00000	481.00000	481.00000	450.00000	475.00000	487.00000
5,500.00000	5,500.00000	5,500.00000	6,200.00000	5,650.00000	5,846.00000
129.09091	151.45455	151.45455	135.00000	153.98230	162.33322
314,893.00000	353,760.00000	353,760.00000	332,500.00000	386,674.00000	426,135.00000
0.26451	0.25503	0.25503	0.20550	0.27862	0.26976
0.50239	0.43098	0.44179	0.41683	0.43310	0.40519
0.44351	0.42468	0.42468	0.39725	0.44445	0.44904
0.20915	0.17107	0.17047	0.34767	0.15695	0.19916
0.49761	0.56902	0.55821	0.58317	0.56690	0.59481
0.13687	0.11666	0.12802	0.15591	0.10182	0.11577

Lockheed Loader	Dornier 1000 Concept
1,200,000.00000	2,205,000.00000
315,000.00000	595,640.00000
300,000.00000	823,000.00000
440,000.00000	275,500.00000
8,000.00000	10,000.00000
3,500.00000	3,500.00000
650,000.00000	882,000.00000
430.00000	435.00000
14,000.00000	13,994.00000
85.71429	157.56753
360,000.00000	1,106,375.00000
0.26250	0.27013
0.25000	0.37324
0.30000	0.50176
0.54167	0.40000
0.75000	0.62676
0.36667	0.12494

SEAPLANE CAPABILITY

As part of this study, data on large seaplanes and future seaplane concepts was acquired from various sources identified in Table 1. Reference 1 is "Janes All The World Aircraft" and numerous editions were used to gather data because data on a particular aircraft type varied from one volume to another or there was inadequate data in one volume and it had to be supplemented by data from another volume. Therefore, the year span for this data is identified in the references for all aircraft rather than a particular aircraft.

To benchmark the Beriev A-40, which is an amphibious seaplane, the Japanese Shin Meiwa PS-1 was used and these two aircraft represent the only large scale seaplane amphibians in existence. Both of the latter aircraft have the capability to take-off on conventional runways as well as on water. However, for this capability both pay a penalty in payload and/or range.

Little data is available on the take-off and landing performance for the seaplanes. Likewise, the sea states in which they are able to operate in is equally vague. As mentioned in the hydrodynamics section it is important that WIG's of different designs be evaluated against common wave spectra and that the evaluation methods be identical. This is also true of seaplanes. Cruise performance and aerodynamic design evaluations of each of the concepts need to be done using common assumptions and methodology. In addition, when range is assessed, different manufacturers use differing standards for calculating reserve fuel. These range anomalies were ignored for this effort.

Owing to time constraints, certain specific assumptions were made. For the Saunders Roe Princess, the range with reserves was considered to be 90% of the still air range. For the NAWC(AD) 2.5M BFS seaplane, the range was calculated at approximately 1/2 fuel load assuming an L/D of 17 and an engine s.f.c. of 0.52 at Mach 0.82.

Table 1, below, presents the gross weights of seaplanes and seaplane concepts considered. These bracket the data presented on WIG's up to 1250 metric tons.

TABLE 1

Seaplane	Maximum Take-off Gross Weight (lbs)	Reference
Shin Meiwa PS-1	94,800	1
Beriev A-40	189,595	1
Martin P-6M	175,000	2
Saunders Roe Princess	340,000	1
Hughes Spruce Goose	400,000	1
Dornier 1000 Concept	2,205,000	3
NAWC(AD) 2.5M lb BFS Concept	2,295,556	4
Beriev 2000 Concept	2,755,775	5

Figure 1 shows the thrust to weight ratio plotted against gross weight for various seaplanes/flying boats. The amphibians shown are the Shin Meiwa PS-1 and the Beriev A-40. The Shin Meiwa flying boat uses a complex system of high lift devices including boundary layer control -- blown rudder, flaps and elevators. This blowing is provided by a separate 1,250 EHP gas turbine engine. Normal power is provided by 4 GE T64-1H1-10J engines rated at 3,493 EHP each. Thus the total thrust for the platform to be consistent with the Wingship data is the addition of the blowing and normal powers. The Hughes Spruce Goose is also shown. As can be seen its thrust to weight ratio is extremely low and this may explain its one and only flight which occurred in ground effect. Therefore, because of its low thrust to weight ratio the Spruce Goose was deleted from further consideration. It is anticipated, as the graph shows, that as seaplanes increase in size their overall thrust requirement will decrease owing to reduced profile drag coefficient both in water and in air.

Figure 2 shows the wing loading at MTOW for the seaplanes considered. As can be seen they rarely exceed 100 lbs/ft**2 and are about 40% to 80% of normal landplane loadings. Lower loadings appear to be required to keep the take-off and landing speeds as low as possible in order to prevent unacceptable vertical accelerations and structural loads during take-off and landing especially in rough seas. The Shin Meiwa PS-1 which has a wing loading of 64.84 lbs/ft**2 has a very low take-off speed of 52 knots and approach speed of 47 knots. It has demonstrated taking-offs in 13 foot high waves and 25 knot winds. In short, the low wing loading, efficient high lift devices as well as blowing all contribute to achieving the low take-off and landing speeds while achieving a cruise speed of 230 knots.

Figure 3 shows the empty weight to gross weight ratio for seaplanes and amphibians. As can be seen, amphibious capability results in an empty weight penalty of the order of 6% if the Saunders Roe Princess flying boat fraction is ignored. It is expected and is shown that the empty weight fraction should decrease with aircraft size. This follows the same trend noticed with landplanes, both commercial and military.

Figure 4 shows useful load to gross weight ratio which is directly related to the empty weight fraction and can be used for gaging the payload and range capability. Useful load is the summation of fuel and payload.

Figure 5 shows the projected fuel weight to gross weight ratio for seaplanes. As can be seen as seaplanes approaching 1,000 metric tons, fuel fractions of the order of 48% should be possible.

Figure 6 and 7 show the maximum payload and payload with maximum fuel to weight ratio versus gross weight, respectively. For long range application payload percentages of the order of 12% appear likely, while for shorter ranges the payload percentage may vary between 20% and 40%. Figures 8 and 9 show

the range associated with the maximum payload weight, and maximum fuel load, respectively. As can be seen, with very large seaplanes payload fractions of 30% and ranges of 3,400 nautical miles should be possible while ranges of the order 7,500 nautical miles should be achieved with maximum fuel load with a gross weight of the order of 1,000 metric tons.

Figure 10 shows the cruise speed trend as a function of gross weight. Although Mach number effects can be expected to limit cruise Mach number, as the seaplanes get larger there should be a decrease in parasitic drag coefficient giving rise to a slight increase in cruise Mach number. Whether a net gain results will be dependent on the engine specific fuel consumption characteristics.

References

1. "Janes All The World Aircraft", Editions 1945 thru 1993, Janes Data Division, Janes Information Group Limited, Sentinel House, 163 Brighton Road, Coulsdon, Surrey CR5 2NH, U.K.

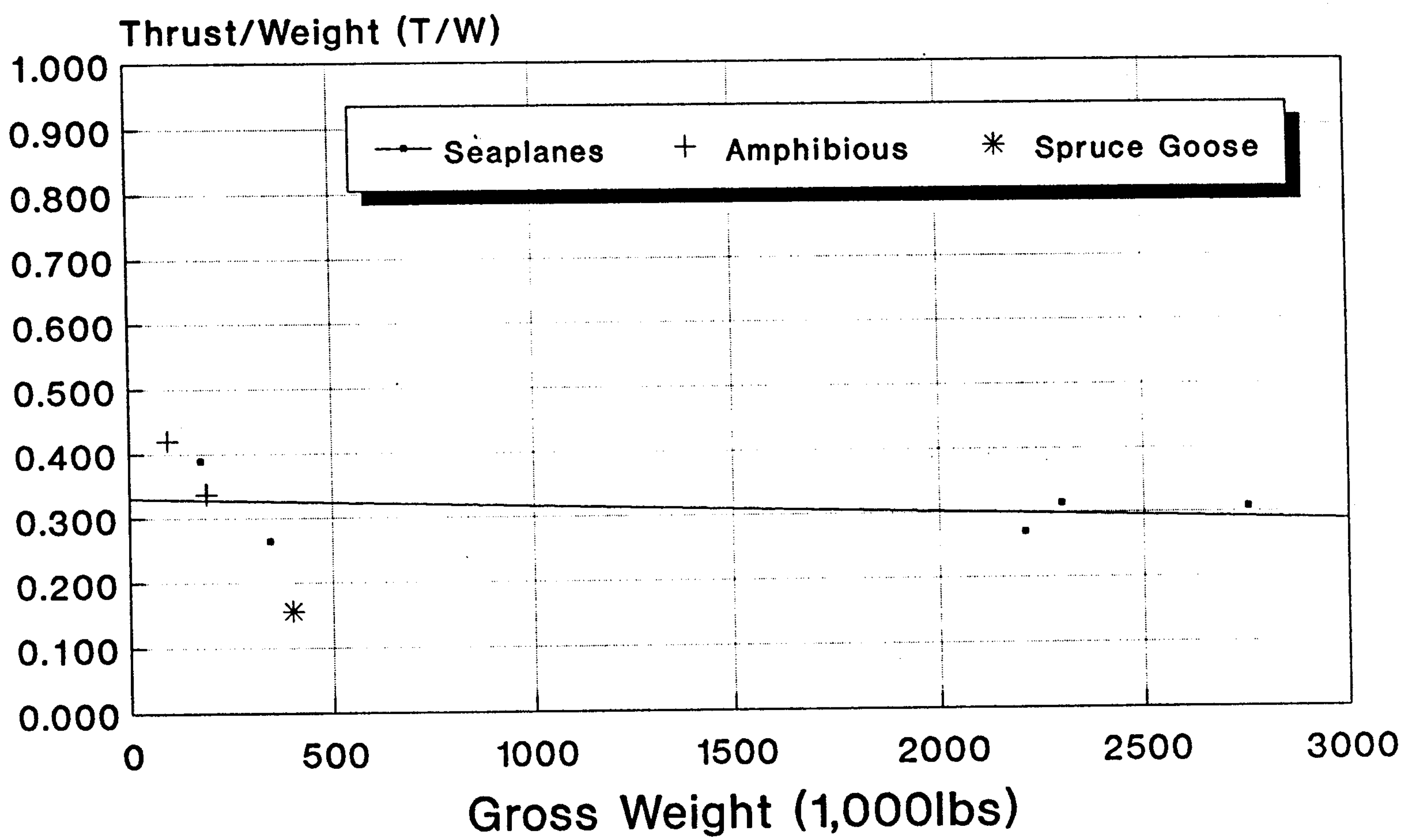
2. Decker. James L., "Design and testing of the Navy P-6M Seamaster Attack Seaplane", Naval Sea Systems Command, Washington D.C. 20362, Reverse Technology Transfer Report, 26 February 1986

3. Dornier Jr., C. " Long Range Very Large Aircraft Supply System for Civil/Military Application with Special Emphasis on Water-Based Aircraft, AIAA Paper 80-0903, May 6 - 8, 1980

4. "BFS - Battle Force Seaplane, Concept Studies Plan", Briefing for NOP -50, Naval Air Warfare Center, Warminster, Pa., Code 6054, 09/08/93

5. Untranslated Beriev Seaplane/WIG paper presented to D. Savitsky, Stevens Institute of Technology, in Russia 08/12/93 during WTET visit.

SEAPLANES
Thrust to Weight Ratio



FIGURE

SEAPLANES

Wing Loading versus Gross Weight

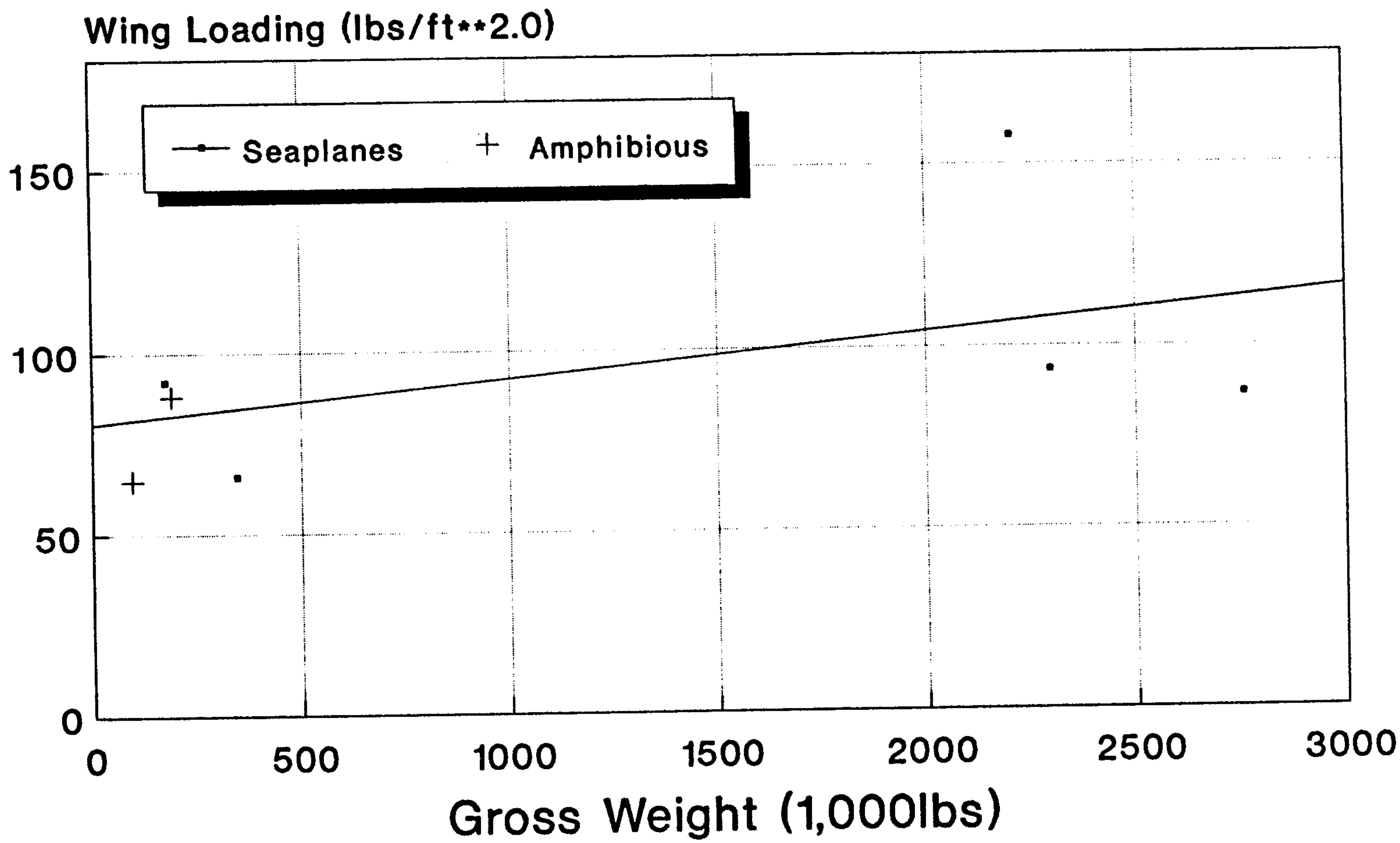


FIGURE 2

SEAPLANES

Empty Weight to Gross Weight Ratio

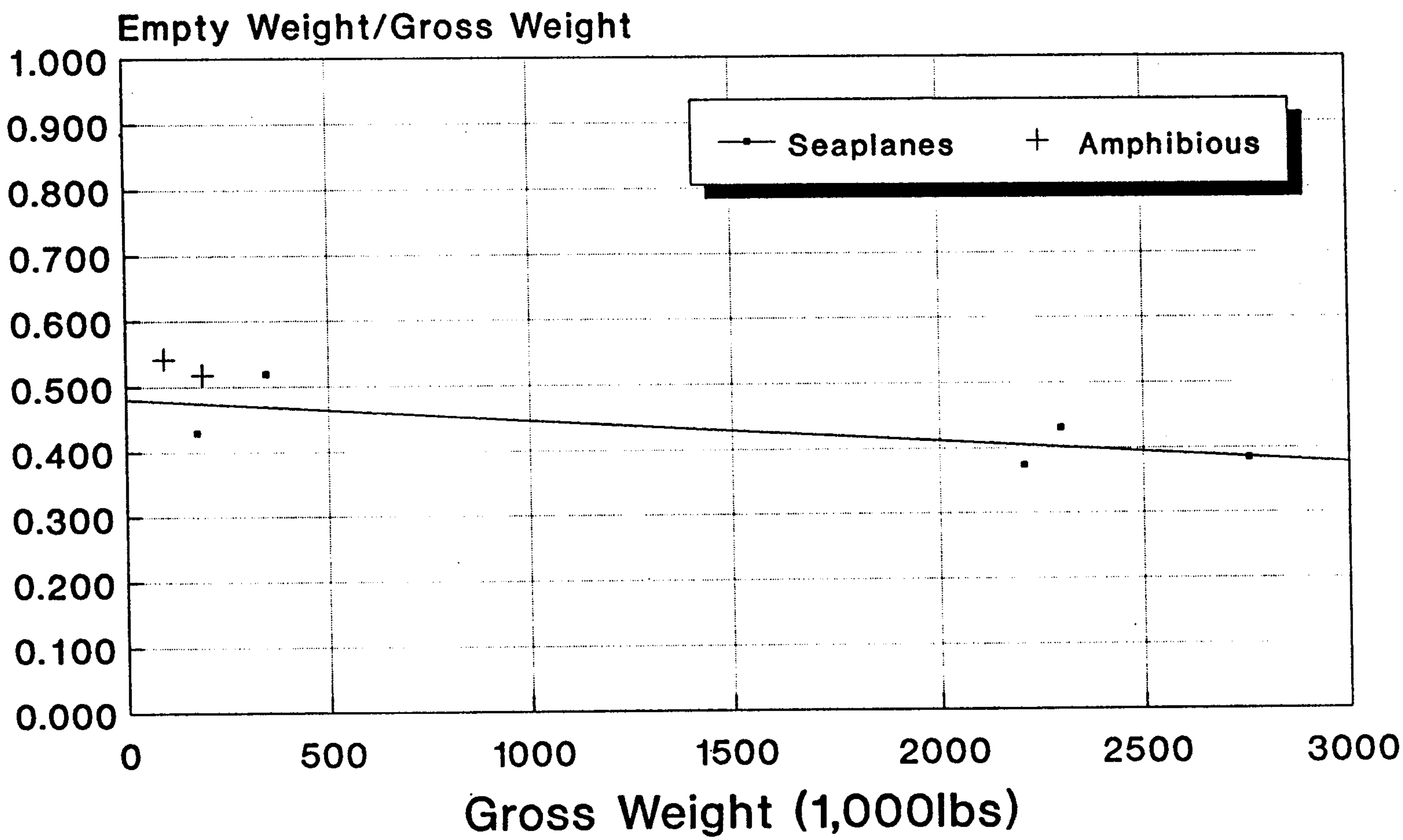


FIGURE 3

SEAPLANES

Useful Load to Gross Weight Ratio

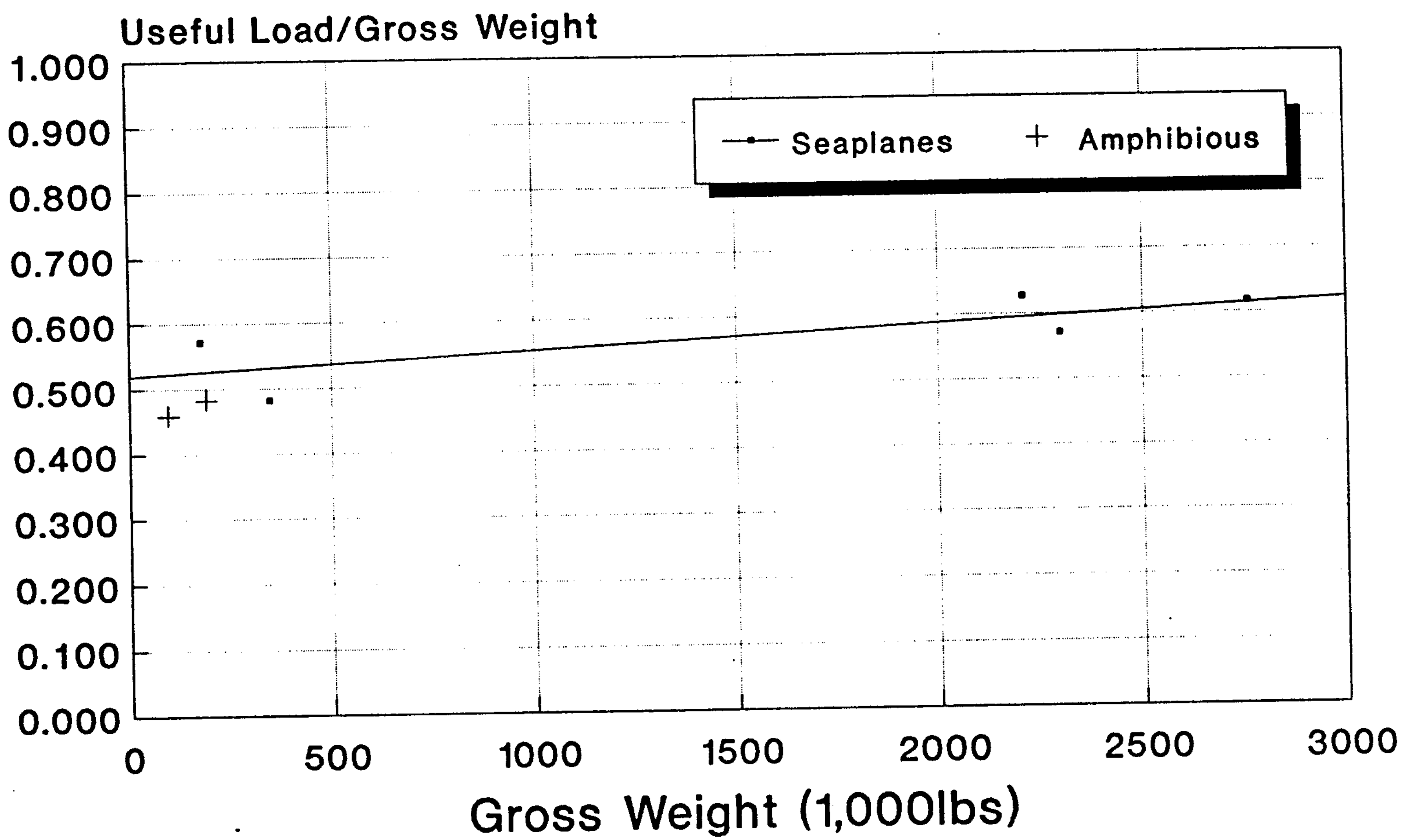


FIGURE 4

SEAPLANES

Fuel Weight to Gross Weight Ratio

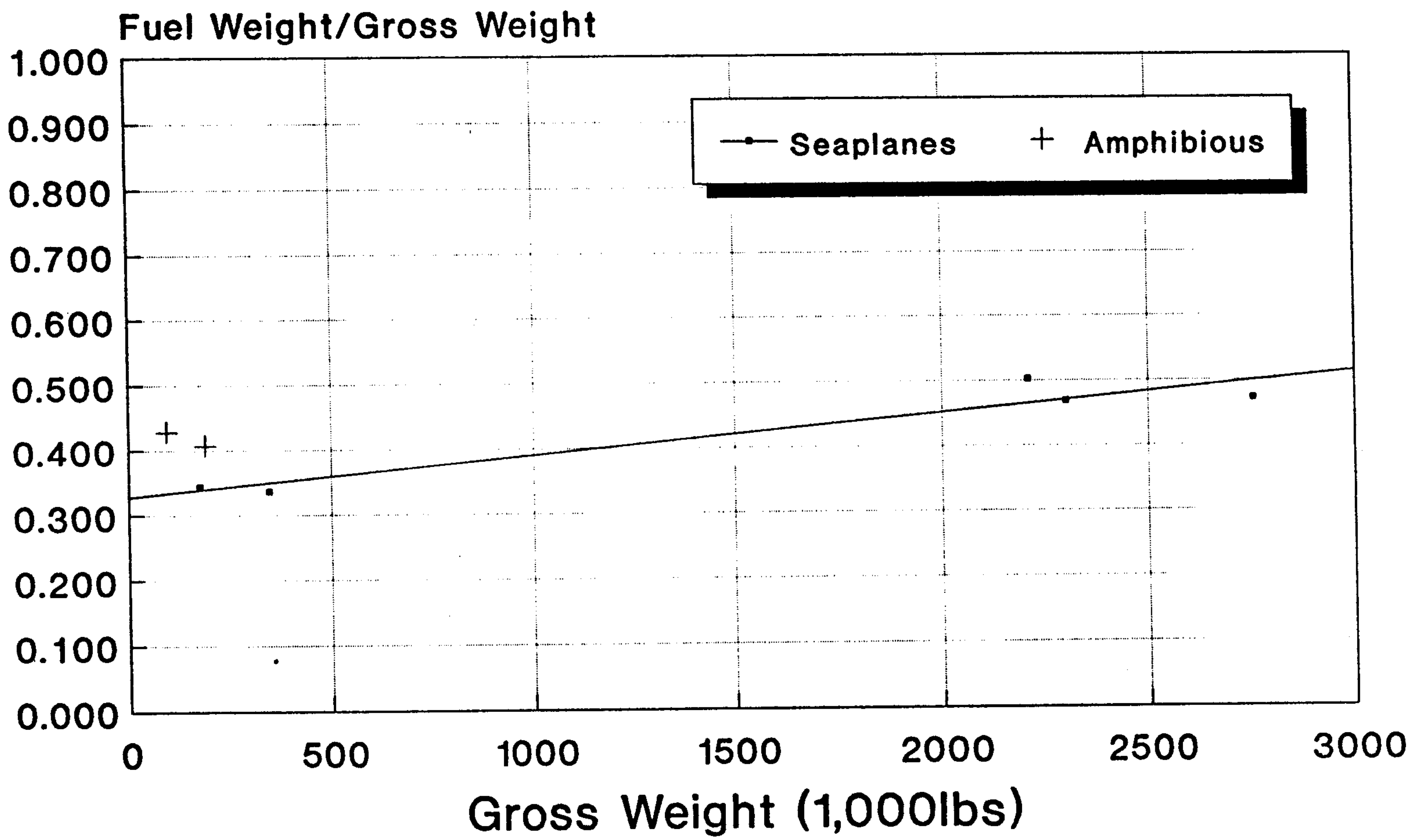
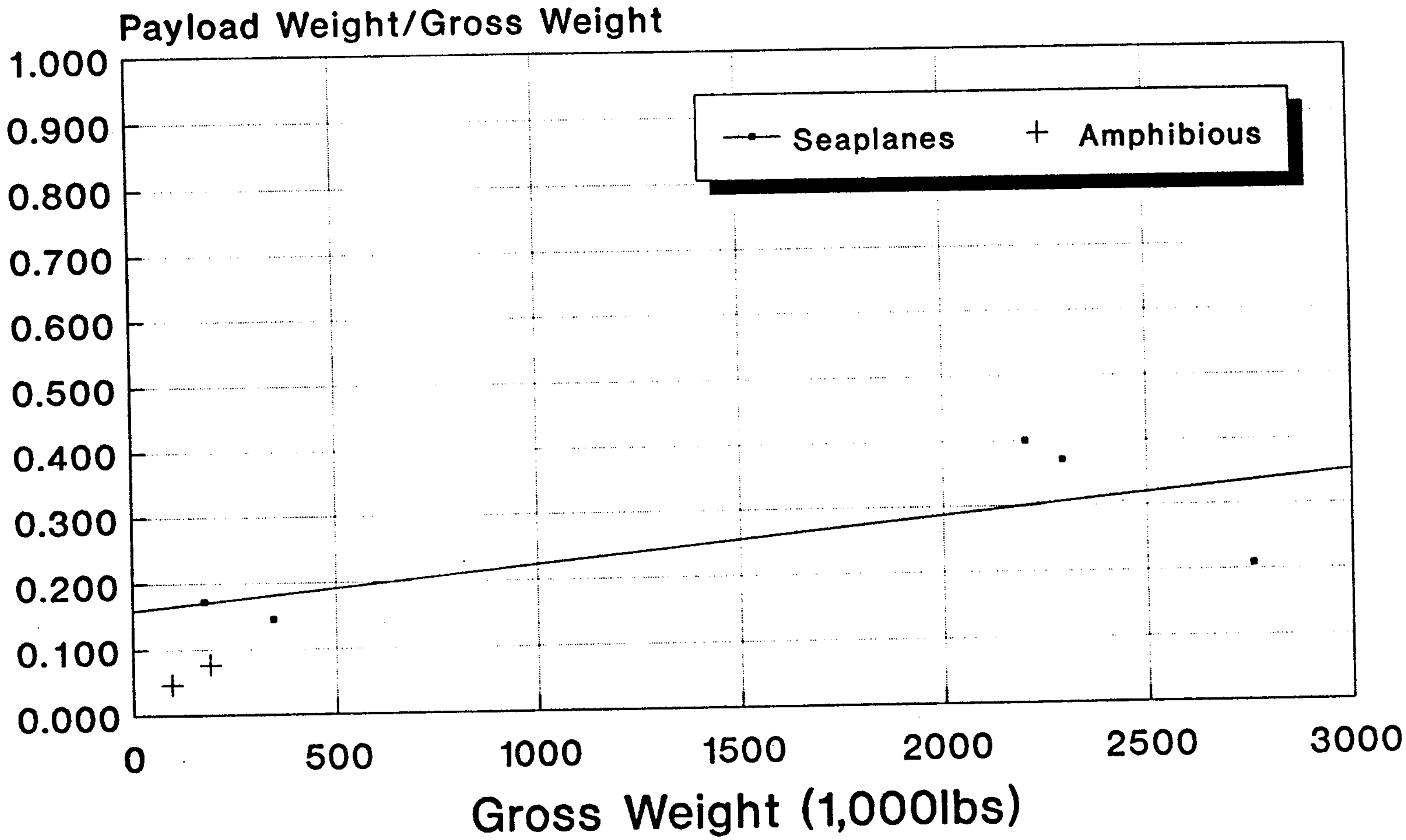


FIGURE 5

SEAPLANES

Payload* Weight to Gross Weight Ratio

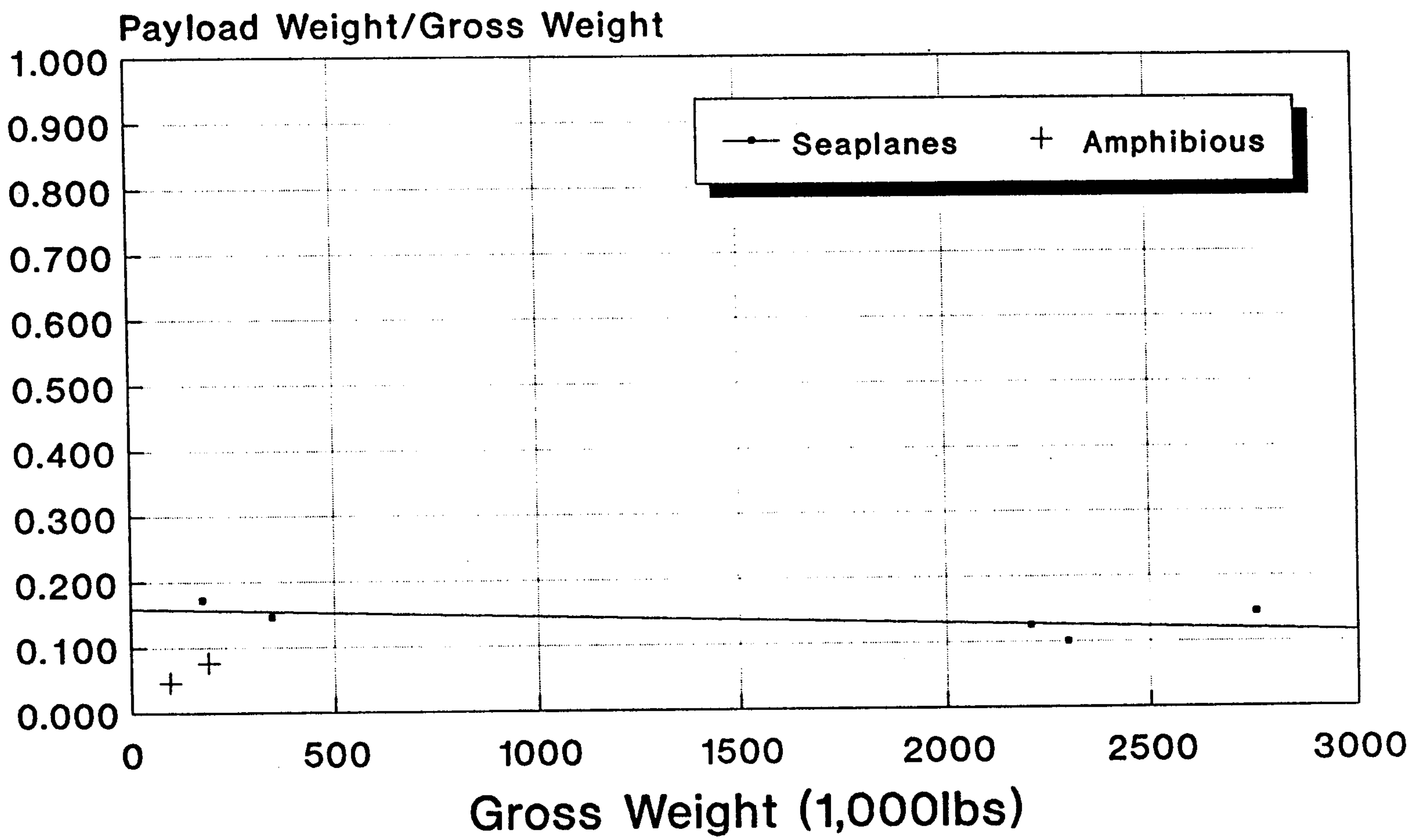


*Note: Maximum Payload

Figure 6

SEAPLANES

Payload* Weight to Gross Weight Ratio



*Note: With Maximum Fuel

FIGURE 7

SEAPLANES
Range @ Max Payload

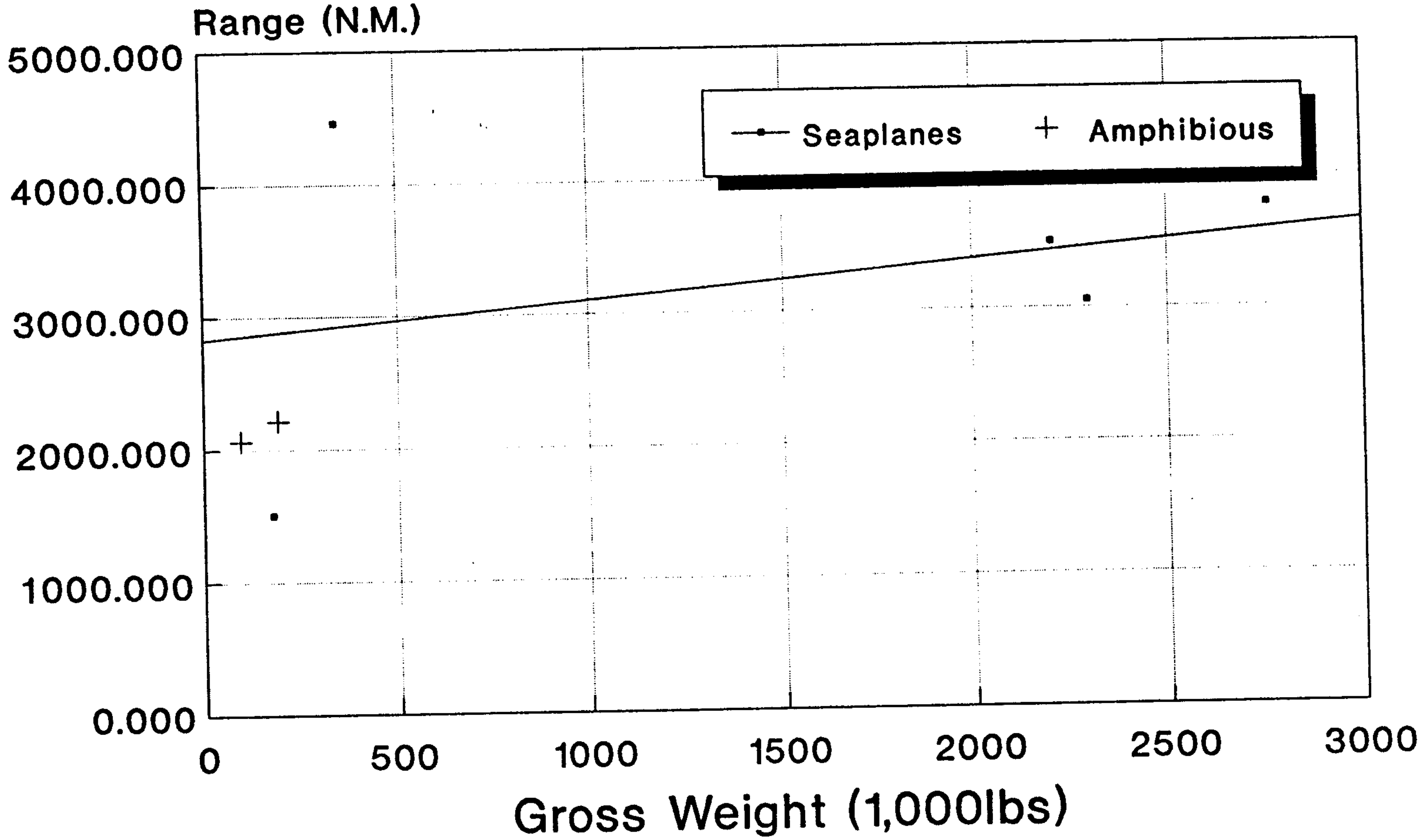


FIGURE 8

SEAPLANES

Range @ Max Fuel Load

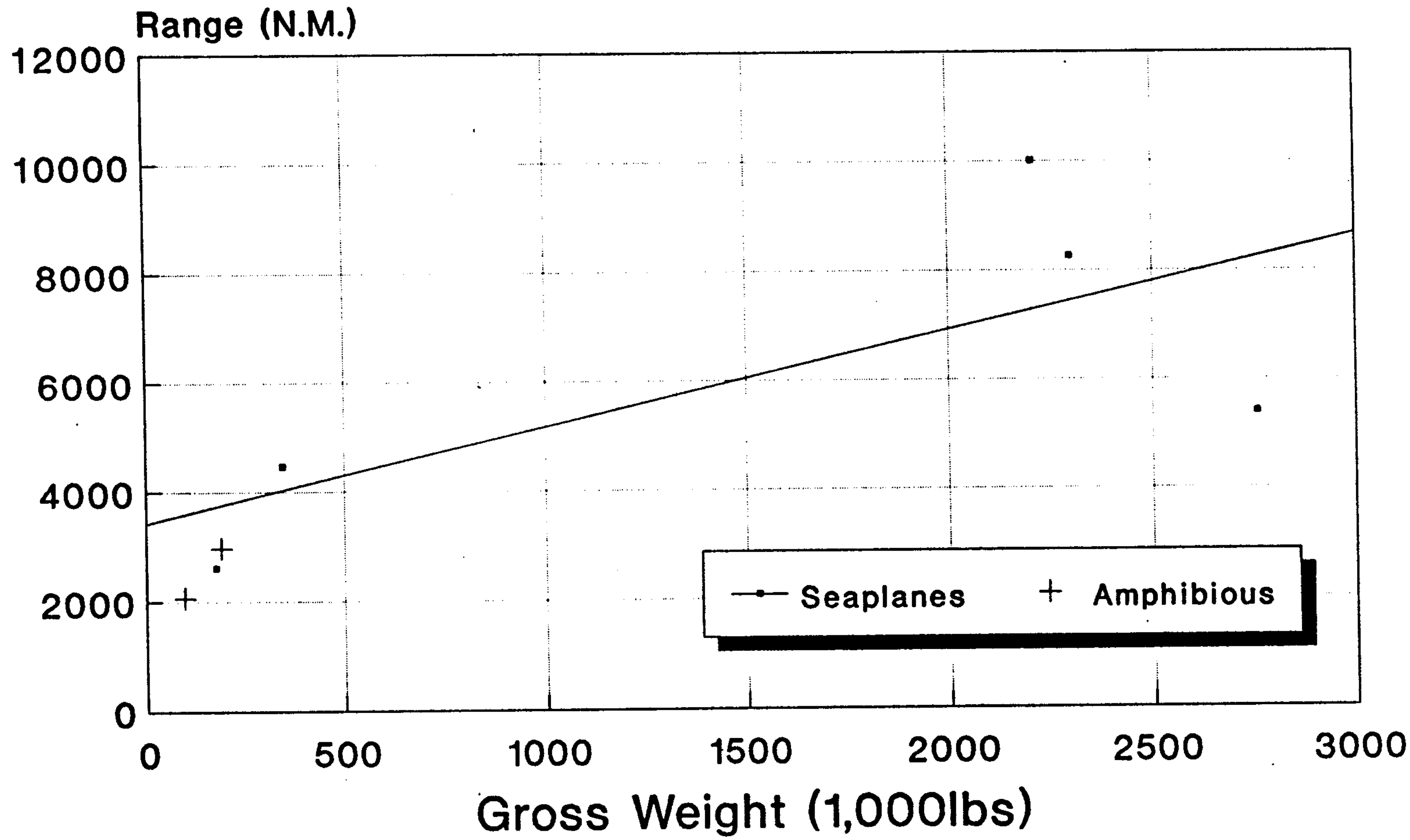


FIGURE 9

SEAPLANES

Cruise Speed versus Gross Weight

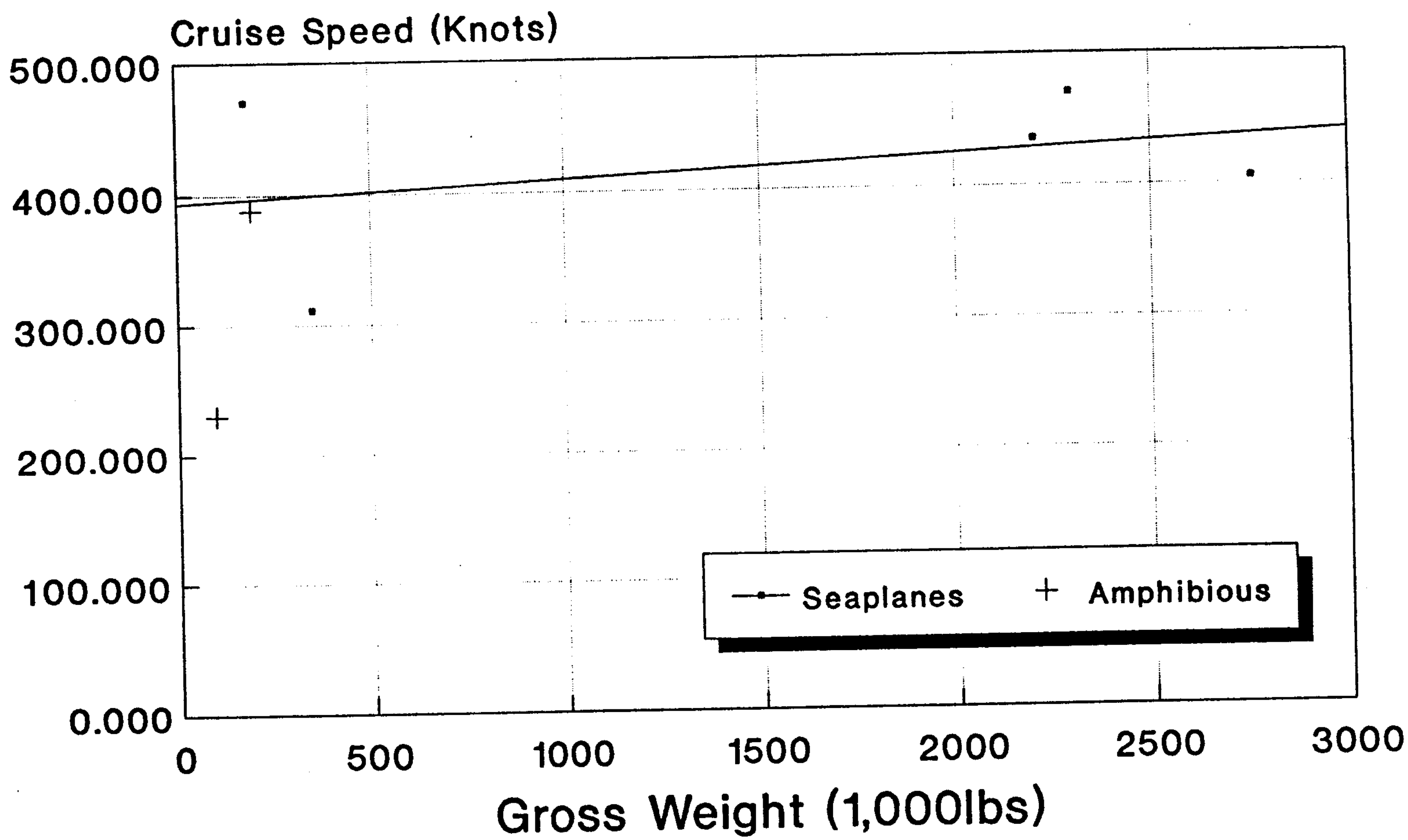


FIGURE 10

Parameter	Shin Meiwa PS-1	Bereiv A-40	Martin P-6M	Saunders Roe Princess
Gross Weight (lbs)	94,800.00000	189,595.00000	175,000.00000	345,000.00000
Thrust, Total (lbs)	39,863.00000	63,930.00000	68,000.00000	91,200.00000
Empty Weight (lbs)	51,367.00000	98,105.00000	75,000.00000	179,000.00000
Payload (lbs)	4,300.00000	14,330.00000	30,000.00000	50,000.00000
Range (n.m.); Max Fuel	2,060.00000	2,967.00000	2,600.00000	4,459.00000
Range @ Max Payload (n.m.)	2,060.00000	2,212.00000	1,500.00000	4,459.00000
Maximum Payload (lbs)	4,300.00000	14,330.00000	30,000.00000	50,000.00000
Cruise Speed (knots)	230.00000	388.00000	470.00000	311.00000
Gross Wing Area (ft**2.0)	1,462.00000	2,153.00000	1,900.00000	5,250.00000
Wing Loading (lbs/ft**2)	64.84268	88.06085	92.10526	65.71429
Max Fuel Weight (lbs)	40,560.00000	77,160.00000	60,000.00000	116,000.00000
Thrust/Gross Weight	0.42050	0.33719	0.38857	0.26435
Empty Weight/Gross Weight	0.54185	0.51745	0.42857	0.51884
Fuel Weight/Gross Weight	0.42785	0.40697	0.34286	0.33623
Maximum Payload/Gross Weight	0.04536	0.07558	0.17143	0.14493
Useful Load/Gross Weight	0.45815	0.48255	0.57143	0.48116
Payload/Gross Weight with Maximum Fuel	0.04536	0.07558	0.17143	0.14493

Dornier 1000 Concept	NAWC(AD) 2.5M lb BFS Concept	Beriev 2000 Concept	Hughes Spruce Goose
2,205,000.00000	2,295,556.00000	2,755,775.00000	400,000.00000
595,640.00000	720,000.00000	846,720.00000	62,400.00000
823,000.00000	987,089.00000	1,058,217.00000	
275,500.00000	229,556.00000	396,832.00000	
10,000.00000	8,260.00000	5,396.00000	
3,500.00000	3,049.00000	3,777.00000	
882,000.00000	849,000.00000	573,201.00000	
435.00000	470.00000	405.00000	
13,994.00000	24,589.00000	31,786.00000	
157.56753	93.35703	86.69776	
1,106,375.00000	1,074,912.00000	1,300,725.00000	
0.27013	0.31365	0.30725	0.15600
0.37324	0.43000	0.38400	
0.50176	0.46826	0.47200	
0.40000	0.36985	0.20800	
0.62676	0.57000	0.61600	
0.12494	0.10000	0.14400	

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Wingship Investigation

Database

Appendix F

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
NASA LWP-490	OCT 67	AERODYNAMIC CHARACTERISTICS OF HIGH FINENESS RATIO VEHICLE BODIES AT CROSS-WIND CONDITIONS IN GROUND PROXIMITY	GRUNWALD, K.J.	R. WILSON
MT-24-2792-74	1970	CRITERIA OF THE LONGITUDINAL STABILITY OF THE EKRANOPLAN	IRODOV, R.D.	R. WILSON
AIAA 72-602	JUL 72	DEVELOPMENT OF THE AXIAL FLOW SURFACE EFFECT SHIP	JACKES, A.M.	R. WILSON
AERONAUTICAL QUARTERLY	FEB 72	SOME STABILITY PROBLEMS OF GROUND EFFECT WING VEHICLES IN FORWARD MOTION	KUMAR, P.E.	R. WILSON
AFFDL FGC-TM-76-5	APR 77	STABILITY DESIGN CRITERIA FOR SURFACE EFFECT AIRCRAFT	LANE, W.H., WELLS, W.R.	R. WILSON
J-TEC ASSOC.	JUN 75	FEASIBILITY STUDY OF A WING IN GROUND EFFECT AS A VIABLE, MULTIPURPOSE PLATFORM	LIPPISCH, A.M., COLTON, R.F.	R. WILSON

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AIAA 69-738	JUL 69	ANALYSIS OF THICK, CAMBERED JET-FLAP AIRFOILS IN GROUND EFFECT	LISSAMAN, P.B.S., SHOLLENBERGER, C.A.	R. WILSON
AIAA 76-865	SEP 76	SEAKEEPING CHARACTERISTICS OF THE AMPHIBIOUS ASSAULT LANDING CRAFT	MAGNUSON, A.H., MESSALLE, R.F.	R. WILSON
DTNSRDC SPD-722-01	AUG 76	THE DISTURBANCE PRODUCED BY AN OSCILLATORY PRESSURE DISTRIBUTION IN UNIFORM TRANSLATION ON THE SURFACE OF A LIQUID	MAGNUSEN, A.H.	R. WILSON
	NOV 69	WIND TUNNEL TEST ON A RAM WING	MILLER, M.K.	R. WILSON
	MAY 70	RAM WING MODEL FLIGHT TESTS	MILLER, M.K.	R. WILSON
NASA TMX-3048	JUL 74	EFFECT OF GROUND PROXIMITY ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF AN ASPECT RATIO-1 WING WITH AND WITHOUT BLOWING	MINECK, R.E.	R. WILSON

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AFFDL TM-75-175-PTB	DEC 76	AERODYNAMIC ANALYSIS OF WINGS MOVING AT SUBSONIC SPEEDS IN THE VICINITY OF A BARRIER	NAGARAJA, K.S.	R. WILSON
NASA CR-2247	DEC 73	THE ELEVATION, SLOPE, AND CURVATURE SPECTRA OF A WIN ROUGHENED SEA SURFACE	PIERSON, W.J, STACY, R.A.	R. WILSON
IITRI PB-189-534	JAN 70	PRELIMINARY STUDY OF AN AUGMENTED RAM-WING VEHICLE CONCEPT	REBA, I.	R. WILSON
	JAN 75	AERODYNAMIC LIFT IN GROUND EFFECT	ROHR INDUSTRIES	R. WILSON
	JAN 76	WATER IMPACT LOADS	SELLARS, F.H.	R. WILSON
	1975	COMPREHENSIVE AUTOMATIC CONTROL SYSTEM FOR SOVIET HYDROFOIL CRAFT TAIFUN	SHPERLING	R. WILSON

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JSR DEC 76	DEC 76	ANALYTICAL DETERMINATION OF SLAMMING PRESSURES FOR HIGH-SPEED VEHICLES IN WAVES	STAVOVY, A.B., CHUANG, S-L	R. WILSON
	1972	ANALYSIS OF THE LONGITUDINAL DISTURBED MOTION OF A SURFACE SKIMMER	VACHASOV, Y.P., KUROCHKA, G.F.	R. WILSON
MIT NO 69-1	JUN 69	AN ANALYTICAL SOLUTION FOR TWO-AND THREE-DIMENSIONAL WINGS IN GROUND EFFECT	WIDNALL, S.E, BARROWS, T.M.	R. WILSON
	MAY 63	WIND TUNNEL INVESTIGATION OF SINGLE AND TANDEM LOW ASPECT RATIO WINGS IN GROUND EFFECT	ONSPAUGH, C.M.	R. WILSON
FTD-ID(RS)T-1432-76	1966	EKRANOPLANS ARE WINGED SHIPS OF THE FUTURE	PIPKO, D	R. WILSON
NASA TM X-3031	JUL 74	INVESTIGATION OF THE STATIC LIFT CAPABILITY OF A LOW ASPECT RATIO WING OPERATING IN A POWERED GROUND EFFECT MODE	HUFFMAN, J.K, JACKSON,C.M.	R. WILSON

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AIAA 81-2077	SEP 81	THE POWER-AUGMENTED-RAM WING-IN-GROUND EFFECT CONCEPT AS AN AIRBORNE AMPHIBIOUS QUICK REACTION FORCE	HEBER, C.E.	R. WILSON
AIAA 79-2032R	JUL 80	HISTORICAL REVIEW OF WIG VEHICLES	OLLILA, R.G.	R. WILSON
DTNSRDC ASED-79-12	DEC 79	CAPTURE OF AN AXISYMMETRIC FREE JET IN A PIPE APPLICATION TO POWER AUGMENTED RAM WING THEORY	CHAPLIN, H.R, MCCABE, E.F., BERMAN, H.A., SMITHEY, W.	R. WILSON
AIAA 79-1864	AUG 79	THE DESIGN IMPACT OF POWER-AUGMENTED RAM TECHNOLOGY ON LARGE ENERGY EFFICIENT AIRCRAFT	MARTIN, C.J., KRAUSE, F.H.	R. WILSON
AIAA 78-752	APR 78	THE CURRENT LEVEL OF POWER-AUGMENTED-RAM WING TECHNOLOGY	KRAUSE, F.H., GALLINGTON, R.W., ROUSSEAU, D.G., KIDWELL, G.H.	R. WILSON
DTNSRDC ASED-365	FEB 76	THE THEORY OF POWER AUGMENTED RAM LIFT AT ZERO FORWARD SPEED	GALLINGTON, R.W., CHAPLIN, H.R.	R. WILSON

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DTNSRDC ACID	JUN76	AN EVALUATION OF A TWO-DIMENSIONAL POWER AUGMENTED WING-IN-GROUND EFFECT MODEL UNDER STATIC AND DYNAMIC FREESTREAM CONDITIONS	PAPADALES, B.S.	R. WILSON
AIAA 76-874	SEP 76	RECENT ADVANCES IN WING IN GROUND EFFECT VEHICLE TECHNOLOGY	GALLINGTON, R.W., CHAPLIN, H.R., KRAUSE, F.H., MILLER, J.A.	R. WILSON
DTNSRDC ASED-379	MAR 77	PERFORMANCE RPEDICTION METHOD FOR A WING IN GROUND EFFECT VEHICLE WITH BLOWING UNDER THE WING	ROUSSEAU, D.G., GALLINGTON, R.W.	R. WILSON
USNA EW 3-77	MAR 77	THE THEORY OF LIFT FOR THE POWER AUGMNTED RAM WING	CARSON, B.H.	R. WILSON
DTNSRDC ASED-385	AUG 77	EVALUATION OF A POWER-AUGMENTED-RAM WING OPERATING IN HEAVE AND PITCH OVER WATER	KRAUSE, F.H.	R. WILSON
DTNSRDC-ASED-383	AUG 77	ASSESSMANT OF LOAD ALLEVIATION VICES INSTALLED ON A POWER-AUGMENTED-RAM WING OVER IRREGULAR WAVES	MCCABE, E.F.	R. WILSON

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DTNSRDC ASED-396	OCT 77	ANALYSIS OF EMPIRICALLY DETERMINED AERODYNAMIC AND RAM COEFFCIENTS FOR A POWER-AUGMENTED-RAM WING-IN-GROUND EFFECT	ROUSSEAU, D.	R. WILSON
MIT/OE 74-14	AUG 74	WAVE RESISTANCE OF ASYMMETRIC PRESSURE DISTRIBUTIONS MOVING IN A CANAL	CHRYSSOSTOMIDIS, C.	R. WILSON
DTMB REPORT 1619	MAR 62	THE WAVE RESISTANCE OF A MOVING PRESSURE DISTRIBUTION IN A CANAL	NEWMAN, J.N., POOLE, F.A.P.	R. WILSON
DTNSRDC REPORT 2121	MAR 74	SOME DESIGN PRINCIPLES OF GROUND EFFECT MACHINES SECTIONS A,B,C,D,F, AND G	CHAPLIN, H.R., FORD, A.G.	R. WILSON
DTNSRDC TM-16-80-19	DEC 80	THE PAR WING SEAPLANE AS A HIGHLY ENERGY EFFICIENT OMNIBASE HEAVY AIRLIFTER	CHAPLIN, H.R, HEBER, C.E.	R. WILSON

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	JUL 88	REVERSE TECHNOLOGY TRANSFER CANDIDATE LWIG		R. WILSON
DTNSRDC SPD-1201-01	SEP 86	WIND AND WAVE ENVIROMENTS FOR FIVE OCEAN LOCATIONS	LEE, W.T.	R. WILSON
	FEB 86	DESIGN AND TESTIN G OF THE NAVY P6M SEAMASTER ATTACK SEAPLANE	DECKER, J.L.	R. WILSON
SIT REPORT 1031	NOV 64	TH EFFECT OF WAVES, LOADING, ANDD CONFIGURATION ON THE TAKE-OFF PERFORMNACE OF WATER BASED AIRCRAFT	VAN DYCK, R.	R. WILSON
		THE WAVE RESISTANCE OF AN AIR CUSHION VEHICULE IN STEADY AND ACCELERATED MOTION	DOCTORS, L.J., AND SHARMA, S.D.	R. WILSON
NASA TN-970	OCT 67	EFFECTS OF GROUND PROXIMITY ON THE LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF AN ASPECT RATIO -1 WING WITH AND WITHOUT END PLATES	CARTER, A.W.	R. WILSON

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		EFFECT OF END RINGS ON THE LIFT OF A WING MOVING OVER THE SURFACE OF THE WATER	FILINCENTO, G.G., AND SHADRIN, V.P.	R. WILSON
		CALCULATIONS OF THE TAKE-OFF AND LANDING OF AN AIRFOIL SURFACE EFFECT SHIP STARTING FROM THE WATER	RUDOMANOV, V.I.	R. WILSON
NASA TM-828	JAN 37	GROUND EFFECT THEORY AND PRACTICE	PISTOLESI, E.	R. WILSON
DIA LN 207-76	MAR 76	MAXIMUM AND MEAN VALUES OF THE HYDRODYNAMIC CHARACTERISTICS OF A WING MOVING ABOVE AN UNEVEN SURFACE	BELINSKIY, V.G., ZINCHUK, P.I., NEZNAMOV, V.N., ARISHICHEV, V.A., PUTILIN, S.I.	R. WILSON
AIAA 87-39265 JSASS JOURNAL VOL 35 NO. 397	1987	A NEW CONCEPT OF SURFACE AIRPLANE (POWER AUGMENTED RAM WING)	ANDO, SHIGENORI	J. GERA
DTNSRDC ASED-TM-16-76-97	DEC 76	PARAMETRIC INVESTIGATION OF A POWER AUGMENTED RAM WING WITH LOAD ALLEVIATION DEVICES OVER WATER WAVES OF VARIOUS SEA STATES	MCCABE, E.F	J. GERA

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DTNSRDC TM-16-79/01	JAN 79	POWER AUGMENTED RAM TAKEOFF AND LANDING AIRPLANE COMPARED TO A CTOL AIRPLANE (BOTH HIGH ALTITUDE CRUISE)	CORNING, G	J. GERA
JSASS JOURNAL VOL 38 NO. 443	1990	PAR-WIG -SOME CONSIDERATIONS FOR CONCEPTUAL DESIGN OF PAR-WIG EFFECT VEHICLES	ANDO, SHIGENORI	J. GERA
JSASS JOURNAL VOL 31 NO.	MAY 88	SOME THOUGHTS ON POWER-AUGMENTED-RAM WING-IN-GROUND EFFECT (PAR-WIG) EFFECT VEHICLE	ANDO, SHIGENORI	J. GERA
AIAA 79-1864	AUG 79	THE DESIGN IMPACT OF POWER AUGMENTED RAM TECHNOLOGY ON LARGE ENERGY EFFICIENT AIRCRAFT	MARTIN, C.J., KRAUSE, F.H.	J. GERA
AIAA 78-1466	AUG 78	CONCEPTUAL DESIGN STUDY OF POWER AUGMENTED RAM WING IN GROUND EFFECT AIRRCRAFT	MOORE, J.W.	J. GERA

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AIAA 78-751	APR 78	EXPERIMENTAL OBSERVATIONS OF THE TWO DIMENSIONAL POWER AUGMENTED RAM WING OPERATED STATICALLY OVER WATER	CARSON, B.H.	J. GERA
DTNSRDC ASED-79-12	DEC 79	CAPTURE OF AN AXISYMETRIC FREE JET IN A PIPE WITH APPLICATION TO POWER AUGMENTED RAM WING THEORY	CHAPLIN, H.R., MCCABE, E.F., BERMAN, H.A., SMITHEY, W.	R. WILSON
DTNSRDC ASED-395	SEP 77	THE PERFORMANCE OF A CONCEPTUAL MULTIMISSION POWER AUGMENTED RAM WING-IN-GROUND EFFECT VEHICE	PAPADALES, B.S.	R. WILSON
DTNSRDC ASED-389	SEP 77	EFFECT OF TURBULENT JET MIXING ON THE STATIC LIFT PERFORMANCE OF A POWER AUGMENTED RAM WING	SMITHEY, W., PAPDALES, B., CHAPLIN, H.	R. WILSON
DTNSRDC ASED-396	OCT 77	ANALYSIS OF EMPIRICALLY DETERMINED AERODYNAMIC AND RAM COEFFICIENTS FOR A POWER AUGMENTED RAM WING IN GROUND EFFECT	ROUSSEAU	R. WILSON

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DTNSRDC ASED-365	FEB 76	THEORY OF POWER AUGMENTED RAM LIFT AT ZERO FORWARD SPEED	CHAPLIN, H.R.,	R. WILSON
DTRC SD-90-07	JAN 09	APPLICATION OF AN AMPHIBIOUS POWER AUGMENTED RAM WING-IN-GROUND EFFECT SEAPLANE TO TH TRANSPORTATION REQUIREMENTS OF THE ASSAULT FOLLOW-ON ECHELON	SMITH, GARY R.	R. WILSON
AD-B044603L	AUG 76	ASSESSMENT OF WING-IN-GROUND EFFECT VEHICLE TECHNOLOGY, VOL 1	GALLINGTON, R., SEKELICK, M.	R. GALLINGTON
AD-C020531L	AUG 76	ASSESSMENT OF WING-IN-GROUND EFFECT VEHICLE TECHNOLOGY, VOL 2	GALLINGTON, R., SEKELICK, M.	R. GALLINGTON

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AD-C-009119L	DEC 76	SOVIET WING-IN-GROUND EFFECT VEHICLES: THEIR DEVELOPMENT, USE, AND FUTURE CHARACTERISTICS	HAMILTON, S.H., KAUFHOLD, F.F.	J. GERA
JSASS JOURNAL VOL 38 NO. 443	1990	RANGE PERFORMANCE OF WING-IN-GROUND EFFECT VEHICLE	ANDO, SHIGENORI	J. GERA
MITSUBISHI HEAVY INDUSTRIES TECH REVIEW, VOL 28	JUN 91	DEVELOPMENT OF WING-IN-GROUND EFFECT CRAFT 'MARINE SLIDER' FOR HIGH SPEED BOATING AND GLIDING FOR SPORTTS AND PLEASURE	MATSUBARA, T., HIGASHIDA, A., MATSUOKA, T., YAMAGUCHI, N., URAGAMI, K.	J. GERA
JSASS JOURNAL VOL 39, NO. 448	1991	PRACTICAL APPLICATION OF THE WING-IN-GROUND (WIG) EFFECT VEHICLE	KUBO, S., KAWAMURA, T., MATSUBARA, T., MATSUAKA, T.	J. GERA
AIAA 88-2527	APR 90	WIND TUNEL INVESTIGATIONS OF WING-IN-GROUND EFFECT	CHAWLA, M.D., EDWARDS, L.C., FRANKE, M.E.	J. GERA

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ISCFD 1989	1989	NUMERICAL SIMULATION OF WING-IN-GROUND EFFECT	KAWAMURA, T., KUBO, S.	J. GERA
	MAY 87	RAM WING AND GROUND EFFECT CRAFT: PROCEEDINGS OF THE SYMPOSIUM, MAY 1987		J. GERA
AIAA JOURNAL VOL 24	JUL 86	LIFTING-LINE SOLUTION FOR A SYMMETRICAL THIN WING IN GROUND EFFECT	PLOTKIN, A., TAN, C.H.	R. WILSON
AIAA 86-1765	JUN 86	EULER CALCULATION FOR FLOW OVER A WING-IN-GROUND EFFECT	DEESE, J.E., AGARWAL, R.K.	J. GERA
AIAA 84-2429	NOV 84	WING-IN-GROUND EFFECT AERODYNAMIC PREDICTIONS USING PANAIR	GOETZ, A.R., OSBORN, R.F., SMITH, M.S.	J. GERA
HSSC VOL 20, MAY 81	MAY 81	SYSTEMS COSTING OF HOVERCRAFT, HYDROFOILS AND WING-IN-GROUND EFFECT MACHINES, VOL I-IV	REEVES, J.M.L., FINDLEY, D.P.	J. REEVES

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**	MAR 80	CLST'S WING-IN-GROUND EFFECT VEHICLES --- AMPHIBIOUS AIRCRAFT DESIGN	CZERNIAWSKIJ, S.T.	R. GALLINGTON
AIAA 79-0845	APR 79	LARGE WING-IN-GROUND EFFECT TRANSPORT AIRCRAFT	LANGE, R.H., MOORE, J.W.	J. GERA
JOA AUG 1978	AUG 78	SOME NONLINEAR EFFECTS IN STABILITY AND CONTROL OF WING-IN-GROUND EFFECT VEHICLES	STAUFENBIEL, R.	J. GERA
AIAA 76-878	SEP 76	PRACTICAL CONSIDERATIONS REGARDING WING-IN-GROUND EFFECT AIRCRAFT	HANDLER, E.H.	J. GERA
NISC-TRANS-3866	OCT 76	WING-IN-GROUND EFFECT CRAFT, THE FLYING SHIPS	BELAVIN, N.I.	J. GERA
NASA TM-78793	JUL 79	POWERED LOW-ASPECT-RATIO WING-IN-GROUND EFFECT (WIG) AERODYNAMIC CHARACTERISTICS --- CONDUCTED IN LANGLEY V/STOL TUNNEL	THOMAS, J.L., PAULSON, J.W., MARGASON, R.J.	J. GERA

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
DTNSRDC ASED-379	SEP 76	PERFORMANCE PREDICTION METHOD FOR A WING-IN-GROUND EFFECT VEHICLE WITH BLOWING UNDER THE WING	ROUSSEAU, D.G., GALLINGTON, R.W.	R. WILSON
DTNSRDC TM-16-77-116	MAY 77	PERFORMANCE OF WIG(S)	GALLINGTON, R.W.	R. WILSON
AD-B044562L	DEC 76	ADVANCED NAVAL VEHICLE CONCEPT EVALUATION (ANVCE) WIG (OGE FLIGHT CAPABLE TO/L SHELTERED WATER LARGE.	DOUGLAS AIRCRAFT CO.	J. GERA
APJ 815-212	SEP 77	IN GROUND EFFECT CRUISE LOGISTICS WIG (WIGH) SURVIVABILITY, VULNERABILITY, AND LOGISTIC CONSIDERATIONS	AMERICAN POWER JET CO.	J. GERA
APJ 815-20	SEP 77	OUT OF GROUND EFFECT CRUISE WIG (WIGO) SURVIVABILITY, VULNERABILITY, AND LOGISTIC CONSIDERATIONS	AMERICAN POWER JET CO.	J. GERA
AIRCRAFT SYM., NOV 90	NOV 90	WIG TRANSPORTATION EFFICIENCY CONSIDERING THE INFLUENCE OF NO-LOAD SITUATION	ANDO, S.	J. GERA

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
JSASS JOURNAL VOL 34	NOV 91	PAR-WIG PERFORMANCE PREDICTION DURING ACCELERATION FROM WATER-BORNE TO AIR-BORNE	ANDO, S., KATO, M.	J. GERA
JSASS JOURNAL VOL 39 NO. 448	1991	FUNDAMENTAL PHILOSOPHY OF PAR-WIG DESIGN AT USA-DTNSRDC	ANDO, S.	J. GERA
JSASS JOURNAL VOL 33 NO.	MAY 90	CRITICAL REVIEW OF DESIGN PHILOSOPHIES FOR RECENT TRANSPORT WIG EFFECT VEHICLES -- WING-IN-GROUND	ANDO, S.	J. GERA
AIAA 79-2033	OCT 79	AN HISTORICAL REVIEW OF WIG VEHICES	OLLILA, R.G.	R. GALLINGTON
AIAA 89-1495	JUN 89	RFB RSEARCH AND DEVELOPMENT IN WIG VEHICLES	FISCHER, H.	J. GERA
NISC-TRANS-3737	JAN 76	THE KAG-3 WIG AND ITS TRIALS	FILIPCHENKO, G.G.	J. GERA

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
LOCKHEED LFL L-53	MAY 63	WIND TUNNEL INVESTIGATION OF SINGLE AND TANDEM LOW ASPECT RATIO WINGS IN GROUND EFFECT (BASIC DATA)	ONSPAUGH, C.M.	R. WILSON
	1980	TH AERODYNAMICS OF UNCONVENTIONAL AIR VEHICLES OF A. LIPSCH, CHPT. IV GROUNG EFFECT MACHINES	BORST, H.V.	R. GALLINGTON
POPULAR MECHANICS	MAY 92	WINGSHIPS	DANE, A.	R. GALLINGTON
DTNSRDC 77-0048	JUN 77	STABILITY AND CONTROL OF GROUND EFFECT AIRCRAFT AND LONGITUDINAL MOTION	STAUFENBIEL, R., YEH, B-T	R. WILSON
PROCEEDINGS FST	NOV 91	EKRANOPLAN: A HIGH SPEED MARINE VEHICLE OF A NEW TYPE	CHUBIKOV, DR. V.	R. GALLINGTON
**	1990	THE EKRANOPLAN - RUSSIAN WINGSHIP TECHNOLOGY, A SPECIAL REPORT	BUSTIN, IAN	R. GALLINGTON

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
AIAA 89-1497-CP	JUN 89	APPLICATION OF THEORY TO HYDROPLANE DESIGN	SCHAFFER, P.E.	J. GERA
AERO QUART, VOL 15	FEB 64	TURBULENT JET FROM A SERIES OF HULLS IN-LINE	KNYSTAUTAS, R.	R. GALLINGTON
81A35724	April 1981	Systems costing of hovercraft, hydrofoils and wing-in-ground effect machines. II	REEVES, J.M.L.; FINDLEY, D.P.	J. REEVES
JSR DEC 1984	DEC 84	A SIMPLE ONE-DIMENSIONAL THEORY FOR AIR-SUPPORTED VEHICLES OVER WATER	TUCK, E.O.	D. CZIMMEK
AIAA, JOURNAL OF AIRCRAFT	DEC 89	NUMERICAL SOLUTIONS OF WINGS IN STEADY AND UNSTEADY GROUND EFFECTS	NUHUIT, A.O., MOOK, D.T.	D. CZIMMEK
TM 16-77-107	JAN 77	APPROXIMATE FORCES ON HARD WIG END PLATES PENETRATING WAVES AND LIMITS ON YAW ANGLE AND SPEED	GALLINGTON, R.W.	R. GALLINGTON

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
ASED TM-16-76-95	OCT 76	PARAMETRIC INVESTIGATION OF A POWER AUGMENTED RAM WING OVER WATER	KRAUSE, F.H.	R. WILSON
ASED TM-16-76-76	MAY 76	STATIC PERFORMANCE OF A POWER AUGMENTED RAM WING	GALLINGTON, R.W., KRAUSE, F.H.	R. GALLINGTON
DTNSRDC/TM 16-79/01	JAN 79	POWER AUGMENTED RAM TAKEOFF AND LANDING AIRPLANE COMPARED TO A CTOL AIRPLANE (BOTH HIGH ALTITUDE CRUISE)	CORNING, G.	R. WILSON
RAS SYMPOSIUM MAY 87	MAY 87	RAM WING AND GROUND EFFECT CRAFT		J. REEVES
AIAA 89-1495-CP		RFB RESEARCH AND DEVELOPMENT IN WIG VEHICLES	FISCHER, H.	J. REEVES
RADIO CONTROL MODELER	1985	NORTH STAR	MIKULASKO, L.	J. REEVES

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
RADIO CONTROL MODELER	1992	AQUABIRD	MIKULASKO, L.	J. REEVES
AEROCON	JULY 1990	THE WINGSHIP: A MEANS TO ACHIEVE HIGH SPEED OCEAN TRANSPORT	HOOKER, S.	R. GALLINGTON
AFFDL/FCC-TM-76-5	APR 77	STABILITY DESIGN CRITERIA FOR SURFACE EFFECTS AIRCRAFT	LANE, W. H., WELLS, W. R.	E. POPE
AFMC/WPAFB DRAFT	MAY 93	INITIAL COST AND EFFECTIVENESS ANALYSIS FOR A NOTIONAL POWER AUGMENTED RAM WING IN GROUND EFFECT (PAR WIG) TRANSPORT	JANSSEN, R.	GALLINGTON
SRS POINT PAPER		FAN DUCT BURNERS FOR REDUCING THE IMPACT OF WINGSHIP TAKEOFF THRUST UPON ENGINE SIZING	LISTER, E.	E. LISTER
NATIONAL DEFENSE	MAR 93	NATURAL RESOURCE CONCERNS IN MILITARY TRAINING	SIEHL, G.H.	E. LISTER

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
SRS POINT PAPER	MAR 93	THE NEED FOR AN ON-BOARD ENGINE DIAGNOSTIC SYSTEM TO RADIO AHEAD FOR SPARE PARTS TO REDUCE DOWN TIME	LISTER, E.	E. LISTER
JOURNAL OF FLUID MECH VOL 136 1983	1983	NONLINEAR EXTREME GROUND EFFECT ON THIN WINGS OF ARBITRARY ASPECT RATIO	TUCK, E.O.	J. REEVES
JFM VOL 135	1983	SLIDING SHEETS: LUBRICATION WITH COMPARABLE VISCOUS AND INERTIAL FORCES	TUCK, E.O.	J. REEVES
JFM VOL 117	1982	ANALYSIS OF SMALL ASPECT RATIO LIFTING SURFACES IN GROUND EFFECT	NEWMAN, J.N.	J. REEVES
JFM VOL 98	1980	A NONLINEAR UNSTEADY ONE-DIMENSIONAL THEORY FOR WINGS IN EXTREME GROUND EFFECT	TUCK, E.O.	J. REEVES
LENINGRAD SHIPBUILDING INST. TRANS #65	1967	INFLUENCE OF VISCOSITY ON PROFILE LIFT AND DRAG NEAR A SCREEN	VOYTKUNSKIY, Y. I., FADDEYEV	J. REEVES

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
AVIATSIONNAYA TEKHNIKA VOL 12, NO. 4	1969	INFLUENCE OF AIR COMPRESSIBILITY ON THE AERODYNAMIC CHARACTERISTICS OF A WING MOVING AT SUBSONIC SPEED NEAR THE EARTH	ERMOLENKO, S.D., KHRAPOVITSKII, V.G.	J. REEVES
RAND R-2243-AF	MAR 78	ESTIMATED COST OF EXTENDED LOW RATE AIRFRAME PRODUCTION	DREYFUSS, D.J., LARGE, J.P.	J. REEVES
AER. JOURNAL MAR 87	MAR 87	AERO-MARINE DEISGN AND FLYING QUALITIES OF FLOATPLANES AND FLYING BOATS	STINTON, D.	J. REEVES
BOOK	1967	SEA SPECTRA SIMPLIFIED	MICHEL, W.H.	J. REEVES
HMSO	1967	OCEAN WAVE STATISTICS	HOGBEN, N., LUMB, F.E.	J. REEVES
NASA TN D-5676	FEB 70	HANDLING QUALITIES OF THE XB-70 AIRPLANE IN LANDING APPROACH	BERRY, D.T., POWERS, B. G.	J. REEVES

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
INDUSTRY WORKING GRP 4TH REV	1990	CTOL TRANSPORT AIRCRAFT CHARACTERISTICS, TRENDS AND GROWTH PROJECTIONS	INTERNATIONAL AIR TRANSPORT ASSOC.	J. REEVES
RAND RPT R-3255-AF	DEC 87	AIRCRAFT AIRFRAME COST ESTIMATING RELATIONSHIPS - STUDY APPROACH AND CONCLUSIONS	HESS, R.W., ROMANOFF	J. REEVES
RAND R-4016-AF	1991	ADVANCED AIRFRAME STRUCTRAL MATERIALS	RESETAR, S.A., ROGERS, C.J, HESS, R.W.	J. REEVES
RAND N-2283/4-AF	DEC 87	AIRCRAFT AIRFRAME COST ESTIMATING RELATIONSHIPS - ATTACK AIRCRAFT	HESS, R.W., ROMANOFF	J. REEVES
RAND N-2283/3-AF	DEC 87	AIRCRAFT AIRFRAME COST ESTIMATING RELATIONSHIPS - BOMBERS AND TRANSPORTERS	HESS, R.W., ROMANOFF	J. REEVES
RAND N-2283/1-AF	DEC 87	AIRCRAFT AIRFRAME COST ESTIMATING RELATIONSHIPS - ALL MISSION TYPES	HESS, R.W., ROMANOFF	J. REEVES

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
AERONAUTICAL JOURNAL VOL 97, NO. 961	JAN 93	EXPERIMENTS ON A 60 DEGREE DELTA WING WITH VORTEX FLAPS AND VORTEX PLATES	RINOIE, K.	J. REEVES
JOURNAL OF AIRCRAFT VOL 23, NO. 5	MAY 86	GROUND EFFECT ON SLENDER WINGS AT MODERTAE AND HIGH ANGLES OF ATTACK	ER-EL, J., WEIHS, D.	J. REEVES
NASA CONF PUB 2319	1983	WIND TUNNEL WALL INTERFACE ASSESSMENT/CORRECTION 1983	NEWMAN, P.A., BARNWELL, R.W.	J. REEVES
NASA CONTR RPT 3882	MAR 85	PORPELLER PROPULSION SYSTEM INTERGRATION - STATE OF TECHNOLOGY SURVEY	MILEY, S.J., LOVANTE, E. VON	J. REEVES
NASA SUPPLEMENT RPT 3840	FEB 85	SYSTEMS STUDY FOR AN INTERGRATED DIGITAL ELECTRIC AIRCRAFT (IDEA)	TAGGE, G.E., TRISH, L.A., BAILEY, A.R.	J. REEVES
NASA RPT 4102	DEC 87	SIMULATION STUDY OF FLIGHT DYNAMICS OF ELASTIC AIRCRAFT	WASZAK, M.R., DAVIDSON, J.B., SCHMIDT, D.K.	J. REEVES

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
NASA TECH PAPER 2414	JAN 85	DOWNWASH IN A PLANE OF SYMMETRY OF AN ELLIPTICALLY LOADED WING	PHILLIPS, J.D.	J. REEVES
RAND R-1854-PR	MAR 76	A COMPUTER MODEL FOR ESTIMATING DEVELOPMENT AND PROCUREMENT COSTS OF AIRCRAFT (DAPCA-III)	BOREN JR., H.E.	J. REEVES
NASA RPT 182066	NOV 90	TASK TAILORED FLIGHT CONTROLS: VOLUME 1 - ULTRA PRECISION APPROACH LANDING SYSTEMS	MITCHEL, D.G., APONSO, L.B., MCRUER, D.T.	J. REEVES
CANADIAN AERONAUTICS SPACE JRL	JUN 65	AERODYNAMIC CHARACTERS OF WINGS IN GROUND PROXIMITY	SAUNDERS, G.H.	D. CZIMMEK
POLISH JOURNAL BUDOWINOWINCTWO OKRETOWE	NOV 74	RAM-WING VEHICLES AS WATERBORNE TRANSPORT FACILITIES		D. CZIMMEK
INTERSOCIETY HIGH PERFOMANCE MARINE VEHICLE CONF. PAPER	JUN 92	MODELING OF SMART STRUCTURES FOR WINGSHIPS	PAI, P.F., NAYFEH, A.H., MOOK, D.T.	D. CZIMMEK

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REPORT NO.	DATE	TITLE	AUTHOR	CUSTODIAN
INTERSOCIETY HIGH PERFOMANCE MARINE VEHICLE CONF. PAPER	JUN 92	NUMERICAL INVESTIGATION OF NONLINEAR UNSTEADY AERODYNAMICS OF THE WIG VEHICLES	KORNEV, N.V., TRESHKOV, V.K.	D. CZIMMEK
INTERSOCIETY HIGH PERFOMANCE MARINE VEHICLE CONF. PAPER	JUN 92	AMPHIBIAN "A-40" - A STEP IN THE FUTURE OF HYDROAVIATION	PANATOV, G.S., KOBYZEV, G.P.	D. CZIMMEK
INTERSOCIETY HIGH PERFOMANCE MARINE VEHICLE CONF. PAPER	JUN 92	MATCHED ASYMPTOTICS IN AERODYNAICS OF WIG VEHICLES	ROZHDESTEVENSKY, K.V.	D. CZIMMEK
INTERSOCIETY HIGH PERFOMANCE MARINE VEHICLE CONF. PAPER	JUN 92	NUMERICAL SOLUTIONS OF WINGSHIPS	ELZEBDA, J.M., MOOK, D.T., NAYFEH, A.H.	D. CZIMMEK
CRDKNSWC/RD-22-93/99	APR 93	AN ANALYSIS OF THE PERFORMANCE AND STABILITY CHARACTERISTICS OF A PAR-WIG	BRY, WILLIAM A, WALKER, R.L., SMITH, G. R	R. WILSON
CRDKNSWC/TM-22/96	MAR 93	STRUCTURAL WEIGHT ESTIMATE OF A WING-IN-GROUND EFFECT VEHICLE	MCAFEE, D.R., WALKER, R.L.	R. WILSON

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REPORT NO.	TITLE	AUTHOR
CRDKNSWC/RD-22-93/97	WIND TUNNEL INVESTIGATION OF A PAR-WIG MODEL	BERMAN, H. A., WALKER, R.L.
DATE APR 93		CUSTODIAN R. WILSON
CRDKNSWC/RD-22-93/98	TOWING TANK INVESTIGATION OF A PAR-WIG MODEL	WALKER, R.L., BERMAN, H.A.
DATE MAR 93		CUSTODIAN

Wingship Investigation

Trip Reports

Appendix G

June 21, 1993

MEMORANDUM FOR THE RECORD

SUBJECT: Trip Report - Pathfinder Visit to Russia
29 May - 5 June 1993

From: Mike Francis and Roger Gallington

1. **Visitor Cadre**

LtCol Mike Francis	-	ARPA
Dr. Roger Gallington	-	SAIC
Capt. Ed Pope	-	Navy (OCNR)
Anatoliy Shishkin	-	Russian/American Sciences
Richard Aldrich	-	Russian/American Sciences

2. **May 31 - Central Hydrodynamic Design Bureau (CHDB), Nizhny - Novgorad**

Dr. Chubikov (Director) introduced Chief Designer Evgensy Fomin, Aerodynamacist Boris I. Koski, Eaglet Designer Stanislav Aladjin, and several others. He said the Chief designer of the LUN was in Birmingham, England. He introduced a Naval officer who is essentially permanently assigned to CBD. Chubikov suggested an agenda which included a tour of the plant where the second LUN is under construction. Mike Francis introduced our team.

Dr. Chubikov indicated that their major interest was in Wingships, but there are other areas of interest. The four main thrusts of the CHDB are:

i) Hydrofoil Ships/Update and Modifications
- Products in 25 countries
- 34 Vessels in Greece
- They are building some new hydrofoils
- There are new projects
  - Sea Hydrofoil, 250 passengers, 37kt, 3m waves
  - 2 being built in Crimea
  - First being tested in Black Sea
  - Military versions go in 3m waves. Makes 120 km/hr in calm water

ii) Air Cushion Ships (new initiative)
- Have two new craft (70 passenger & 45 ton cargo)
- Good results on speed and efficiency
- 30% more speed on 3% less power
- Simple efficient design
- Mass produced two places in Russia
- Prototype under test - Five orders
- Also working on sea-going air cushion ship about 100-> 120M long

iii) Transport Platforms on the Air Cushion
- They call it dynamic air cushion (DAC)
- It's a lot like the Power Augmented Ram Landing Craft Air Cushion (PARLAC) studied by DTRC a few years ago
- It can move on any surface
- Speeds up to 150 km/hr

iv) Ekranoplan (showed historical background video)
- Have had persistent funding problems
- Will be building CHDB designs at several locations in Russia
- Flap deflection is about 20° in ground effect
- 140 tons (metric), 400 km/hr, 1000 kw
- 5 Orlans built, 2 remain in service

Dr. Chubikov indicated that Volga II is entering mass production. Did not hear locations or customer names. Claimed that LUN could take off and land in 3m waves, Orlan in 1.5m waves. For LUN, this is less than 10% of its length. Eaglet is stationed on shore and is amphibious. Eaglet has a range of 1500 to 2000 km. LUN is moved about on a special floating platform. It has greater range than Eaglet. LUN has been in the water for periods of up to 6 months. All welded construction. Discussed the transport platform or air platform. A lot like PARLAC. Expected performance is speed approximately 200 km/hr; 300 metric tons. This is newest concept. Have done only radio control models within the last 18 months.

Chubikov estimates the floating LUN could survive (but not take off) in Sea State 6 to 7.

Dr. Chubikov said that the quality and detail of our questions indicated that our evaluation was a serious one and that we had selected knowledgeable people for the team. He then proceeded to give his answers to some of our initial questions:

Q: Was it necessary to do flutter analysis and test? **A:** Yes. Was designed to meet Navy specs. Tougher flutter requirements than for aircraft. All requirements were met by prototype. There were 32,000 strain gauges used in LUN airframe test, (note: 18,000 strain gages on Orlan).

Q: What do you consider the best source of scientific and engineering information on Wingships? **A:** The best source is here at CHDB. (I think this is self-serving. We later found a more comprehensive center of expertise at Tsagi).

Then Chubikov asked: What is the U.S. Government's direction or tendency on Wingships? **Our answer** - It depends on the results of this evaluation.

The Orlyanok (Eaglet) was ready for production. Would carry 150 people and some equipment. Managed by two ministries.

Made program difficult. Navy supported program. The defense minister resisted. Application was 'transport and assault'.

Q: Why did the Navy drop the rescue mission? **A:** They didn't. Now two agencies work together to gain experience in certification. Chubikov claimed possible improvements in technical performance of 2-4. Such things as empty weight, life, efficiency. His former aerodynamicist (had left CHDB), thought this was optimistic. They are putting together several design variants for 150 passenger craft.

Dr. Chubikov: Wingships are a breakthrough in transportation. There is Australian and Canadian interest. In Indonesia there are many islands without airports that are the right distance apart. They need a transportation infrastructure. Now looking for a solution. Idea would be to get to islands in about 2 hours with your car. Lufthansa has interest in using them in the Caribbean to attract passengers.

Other possible applications -

- fisheries spend $40M replacing crews on ships and transporting fish out. Wingships could fill a useful role here.

- They also promoted coast guard and drug enforcement/ interdiction roles.

Dr. Chubikov stated that he believes that empty weight penalties due to hydrodynamic loads will be less in larger sizes. He further stated that "there have been no accidents attributed to ship."

Q: Do you ask too much of pilot? **A:** No. Pilot violated rules. Pilots lost alertness. Accident record is better than for conventional aircraft. Craft seems so benign that crew doesn't think they can get hurt. Therefore, they get lazy.

They have flown to altitudes of 100m. Out-of-Ground Effect (OGE) flight is not efficient. Only for obstacle clearance and ferry flights.

Dr. Chubikov indicated no problems in discussing technology with us. Both vehicles (LUN & Orlan) have been used a lot. Navy has requirements to replace equipment when useful life is up. All the vehicles belong to the Navy. And they don't have enough money to continue programs. On a related note, Chubikov indicated that one SES has been sold to Peru. It does 35kt in 2.5M waves.

Concerning the possibility of a large Wingship (Orlan) demonstration this fall: If Navy provides funding, they can go ahead. It will take 2 1/2 months to replace life-limited items. If the vehicles belonged to CHDB, it could be faster. He stated it would take $150-$175M to replace equipment (a first 'offer').

LUN is being modernized. It's a unique vehicle intended for research. LUN will possibly fly next spring. The last Orlan (Orlyanok) left CHDB 12 years ago. They've been in the Caspian since.

Q: What do we have to do with the Navy? Chubikov offered to handle it. Chubikov will speak with Kokoshen. Promised answer by 14 June.

We toured the Volga plant and observed a LUN vehicle under construction: Main step on hull sweeps forward from keel to chine. Afterbody has multiple wedge-like steps that wrap around to a large spray deflector where one would expect a chine. The afterbody has a round Chine. The end plates have multiple steps that wrap around and carry up the sides. On facilities, they have a local wind tunnel and use another at the Joukowski Institute for powered models.

Dr. Chubikov: Need to look for Wingship application, in transportation! As a result of their efforts it is now possible to confidently design big vehicles which can operate over open sea. Need to optimize for that purpose. It we apply best knowledge from both countries, can go up in size. Should strive for AN225 performance in 4000 ton size.

Dr. Chubikov on certification: Should be certified as special category. Not as airplane or hovercraft. At meeting of International Maritime Organization (IMO), we have brought Wingship Certification to international attention including Norway, France, Canada, & Russia. One issue is high speed operation with other slower craft. Russian certifying agency for Wingship was established as a part of existing maritime certifying agency.

CHDB receives many requests for information from all around the world concerning Wingships.

That evening, most of the group from CHDB joined us for dinner at the hotel. In addition to excessive 'toasting', there were lots of Russians all trying to talk at once (which bothered our translator Elena), and made translation difficult. The Russians appear to do "business by toast", that is, they try to extract commitments while building camaraderie. This 'mixing business and recreation' is a significant cultural difference.

3. June 1 - Test facility, near Chkalovsk, Russia

After breakfast at the hotel, we traveled for 2 hours to the test site. It took about 2 hours over very rough roads. The terrain in this area resembles Northern Wisconsin or Minnesota. The test site is on the Gorky Sea, which is actually a man-made lake on the Volga river.

After some short introductory remarks by the chief engineer of the

test site, we went to look at the STRIZH and VOLGA II vehicles. In the process, we met Mr. Bulanov, the Strizh designer and Mr. Yuri Churkin, the pilot. The following observations relate to things noticed that were not expected.

The STRIZH has a small leading edge radius. The joints in the drive shafts are apparently common automotive U-joints. The pivot axis is apparently between the two U-joints and well behind the plane of the props. Therefore, when the props are moved to high angle (i.e., in the PAR position), the center hub of the prop and the front U-joint are higher than they are when the prop axes are more nearly horizontal. There are three or four distinct steps on each endplate which continue up the sides. They "wrap around" the entire endplate. The STRIZH has a span of about 6.6M an aspect ratio of about 3, a length of about 11M and a tail height of about 3M. Its gross weight is about 1.6 tons. It has two 135hp engines. The construction is riveted aluminum.

The VOLGA II has three sealed inflatable bags-- one at each wingtip and one in the centerline. Apparently, the centerline bag is to separate the cushion into two parts for roll stability. Apparently, pitch stability and trim is related to the flow under the wing, flap angle and the PAR propulsion angle.

Each of the bags has little steps or flow separators spaced every couple of inches. This idea of multiple steps and flow separators seems to recur in all CDB designs.

Comparison Table:

	VOLGA II	STRIZH
Gross Weight	2.5mt	1.6mt
Wing Area	$50m^2$	~156 sq. ft.
Installed Power	2x135 hp	2x135 hp
C.G. Position	0.29 to 0.32c	
Fuel Volume	250 liters (?)	
Endurance	3 hr	
Empty Weight	1.8mt	
Craft Density [lb/ cu. ft]	.45	1.8
Cruise Speed		
Cruise C_l		

Note that the VOLGA II is very light ($(W/S)^{1.5} = 0.45$). The STRIZH is much heavier ($(W/S)^{1.5} = 1.8$), and about the same density as models we tested in the 70's.

To view the flight, we boarded a catamaran deck boat and cruised to about a mile off-shore. The water was essentially smooth. Roger suggested they run the STRIZH over the wake of the boat which had waves about 1.5 feet high. They didn't accept this suggestion.

STRIZH flew by first with a clearance varying between about 0.2m and 0.5m. It was in strong ground effect. It has fairly deep endplates. They conducted a single fly-by. We learned later that they intended more but had some engine trouble.

VOLGA II then flew by. The inflatable bags occasionally touched the water. They didn't seem to "stick" and made a "whooshing" noise when they touched. To turn, the vehicle went down into a displacement mode and there was some throttle jockeying -- possibly differential thrust to turn. Performed another straight fly-by. Flap was nearly faired. When at low speed on PAR, there was quite a bit of blow-back -- especially at the tips. The craft is very light for its size. Made two additional flybys with more clearance -- apparently 0.2m.

While we were awaiting the next fly by, we asked about operational experience with Orlyanok. Engines last about 500 hours. They ran the engines about 100 hours per year. They have changed the whole set of engines on the Orlyanok about 4 times. They paint the underwater parts of the craft with anti-fouling paint to control marine growth. They have a corrosion control program that includes washing engines, cleaning, and coatings. As we motored back to the dock, we saw them lifting STRIZH out of the water for engine work. They then took us on a tour of the laboratories while they worked.

Their closed circuit wind tunnel with an open test section is a relic from the past. It was allegedly designed specifically for surface effect work by Alexeev himself. Diameter of test section is about 2m. Speed ranges from 50 to 150 m/sec. Ground simulated by plate with streamlined leading edge or by image method. A wire-truss type, 6-component balance provides minimal aerodynamic interference at the expense of difficulty in setting model attitude. Vintage 1950's instrumentation. Turbulence level was advertised at 0.5%.

There were a couple of unusual vehicle test models in the work areas. One had wing panels angling up from the tip plates. They all had hydrodynamic steps, chines, and other flow separators. One model had twin tail booms.

We saw a large circular tank with a whirling arm. In addition to the usual steady state high speed testing, they build model beaches and obstacles in their tank.

We saw a high speed carriage over a 200m long tank for testing powered models. Advertised speed was approximately 25m/sec. The carriage was light, and all the instrumentation was stationary. Communication from sensors on the model or carriage was apparently through a cable that was initially along the bottom of the tank and which the carriage picked up and dragged along. The cable was apparently a little more than twice the length of the run and attached to the facility about in the middle of the tank and to the carriage at the other end.

After the tour, we were told that they had fixed STRIZH (ignition problem) and suggested we take the faster (than the catamaran) small hydrofoil boats to the fly-by site. Their very old boat designs were impressive. They would easily carry 6 people at 27kts with the ~120 hp Cheka engine turning at 3400 RPM.

Here are the key observations in the second, more lengthy set of STRIZH fly-bys.

We observed:

i) Straight IGE with tips about 0.2m clearance;

ii) Landing with props in PAR position. Then taxied on PAR at about 15kt. Then T.O. with lots of light spray. Went by on PAR with props at about 30°;

iii). Another high-speed straight run with some light occasional water contact. No perturbation was evident. The multiple steps apparently permit water contact over a fairly wide range of pitch altitudes;

iv) Over flew one of the boats. Landed and turned in a PAR-taxi. Waves about 3 inches;

v) Smooth run at about 0.5m clearance;

vi) An O.G.E. pass at about 30m with an intentional wing-rock.

Our boat driver started the engine each time the STRIZH approached. Never asked why. Later, Roger asked the test pilot, Yuri Chirkin, about how he handled the PAR. For takeoff, he leaves the props in the PAR position until airborne. Reverse procedure for landing. That is, go to PAR position just before touchdown would occur without PAR.

Our hosts took us to the local small town (Chkalovsk) named after a famous Russian Aviator (Valery Chkalov). He and his navigator made a 63 hour flight over the pole from Moscow to Vancouver, Washington in 1937. Some data for comparison with Wingship.

Gross Weight	=	11 tons
Fuel Weight	=	6 tons
Empty Weight	=	5 tons

A 45% empty weight fraction for a high aspect ratio aircraft made from corrugated aluminum and covered with fabric! With its 960hp single engine, it had a power loading of over 25 LB/HP.

We then returned by Van to Nizhni Novgorad and another (very late) toast-filled meal.

4. June 2 - Oktoberskiaya Hotel, Nizhny-Novgorad:

After breakfast, we had a caucus without the Russians to summarize our thoughts. Here are topics discussed:

- Plan for August trip details and possibility of a large vehicle demonstration in September
- The tendency of the Russians to have overly optimistic expectations
- Sharing our parametrics and point design performance estimations for their critique as a means of extracting more documentation from them.
- Site visits and demonstrations planned for WTET visit.
- Number of interpreters and guides required.
- Additional questions:
  - Who is real customer for LUN?
  - What is schedule for next LUN flight?
  - What is historical man-loading on Wingship projects?
  - Are the existing LUN and Orlyanok being actively maintained at Caspisk?

We also concluded that the group from CHDB was trying to occupy all of our time to prevent us from talking to other Wingship experts. We decided to force meetings with at least Sinitzen and Panchenkov. We received a card and note from Panchenkov the previous evening.

In early afternoon, we met again with the CHDB folks including Boris Chubikov. Here are the key points. (BC=Chubikov, MF=Francis)

BC:
- LUN cannot be ready for demo before Spring '94
- Wants to concentrate on feasibility assessment and exclude many of our specific questions
- Emphasis that U.S. could undoubtedly build Wingship but Russian involvement would speed the process
- Emphasized the talent of designers and their knowledge of the sea-air environment.
- Experience is important in flying near the sea.
- Russia isn't the sole repository of Wingship understanding. But - it's the most important.

MF
- A joint experimental program could be a very good example of cooperation between the two countries.

BC
- Started estimate of costs for Orlyanok demo. Will complete estimate in 2 or 3 days.

MF
- Described a fixed price contract with management reserve as a possible way to fund demonstration.

BC

- Asked for opportunity to use management reserve for other things! (Showed he didn't understand concept) Suggested large scale investigation of seaworthiness. May have difficulty getting Navy concurrence. Probably need intergovernmental agreement. Will tailor demo to show things of interest to us. We tell him what they are, and he will put in flight plan.

BC - Comments and Observations:

- What is the U.S. view on creating a rescue team at international level? 2 Wingships (LUN type) in Norwegian Sea. Others might cooperate. Use existing LUN wingships. Good first operational mission.

- Would like to know guidelines for cooperation of countries. What is mission? Would like to know our vision as soon as possible.

We met with Panchenkov in the afternoon. Here are the main points from that conversation. Panchankov believes that it is impractical to jump from small craft to 5000 ton size vehicle. He also believes that it is impractical to convert military designs to commercial use. He showed a series of sketches of different configurations for different weights ranging form 1.2 tons to 3000 tons. Each had a different configuration. Panchenkov favors a triplane configuration with two tandem wings in strong ground effect and a larger payload carrying wing (generally above the other two). In addition he talked about two fuselages (catamaran) that provided a straight side to make docking easy. He stated that smaller craft required proportionally larger lifting surfaces than larger craft. He based opinion on the square cube law but didn't really explain it. He claimed that the aerodynamic efficiency of the three plane configuration was best, but did not present any data to support this claim other than some academic comparisons of induced drag of tandem and single surface configurations.

Here is some data on his design concepts. In a tandem configuration, he carries about 70% of the weight on the rear surface and about 30% on the front surface. In the triplane configuration he carries about one-third of the weight on each surface. Here is data on one he has flown:

Weight=2.5 ton
Lifting Area=27sqm(main)+10sqm(canard)
Installed Power=216hp
CG Position 70% rear and 30% front
Cruise Speed = 130 km/hr
Take Off Speed = 110 km/hr
Cruise Height = .5 m

A larger craft would have a length of 150m and a span of 50m and would cruse at a height of 5 to 7m.

Panchenkov listed some drawbacks to Hooker's design approach, in his opinion. They are:

- Aircraft configuration is not as good as Panchenkov's.
- Panchenkov square shape is easier to dock.
- Hooker's doesn't have lifting fuselage.
- Not seaworthy enough to survive in open ocean.
- Safety
- Requires too much take off power.

This last comment is especially interesting. Panchenkov claims that the power required for take off for his designs is much less than for Alexeev deigns. Yet he doesn't use PAR or any other apparent take off aid. Therefore, it should just be seaplane hulls all over again. Also, the difference between cruise speed and take-off speed seemed unacceptably low.

The main difference between his design approach and that of Gunter Jorg (in Germany) is that the span of Panchenkov's front surface is smaller than that of the rear.

He says that the Alexeev approach has low vertical stiffness and therefore the designers must concentrate on developing as much stiffness as they can to the detriment of other qualities. He didn't say how his approach overcomes this difficulty.

We promised to send a list of WTET members and their biographies.

Panchenkov is the head of an academic department and claims to deal with science only and to not have his opinions distorted by trying to save a company. He also indicated that if we didn't support him now, we would pay dearly for his help later.

Next, we met with Demitry Sinitzin who is reputed to be the brains behind the LUN. He recently left CHDB, but Wingships are still his main interest. He just started a small firm to promote Wingships. The name of the firm is "Technology In Transport". He asked us if our interest was in all applications or just some. We replied that we were interested in LUN and larger deigns primarily intended for hauling over long distances. Their interest is exclusively in commercial applications for VOLGA II all the way to CSM size. We promised lists of names, bios, and questions.

We traveled by overnight train to Moscow.

5. June 3 - Various locations, Moscow:

Met at Russian-American Sciences (National Academy of Sciences Building) with owners of the large flying Wingships. Met with two military officers, including Navy Captain Yetremov, from the Department of Foreign Economic Relationships, and Col Hdikayev, also in the Russian Navy, assigned to a special department which deals with Wingships.

Yetremov stated that any type of cooperation is overseen by the Government and the President. There is a special company formed to oversee military technical cooperation - named Spetsvneshtekhnika (description attached). An oversight committee reviews all actions. There are three divisions of responsibility. The Association of Defense Experiments deals with heavy military machines, The Special Foreign Technology Division specializes in negotiating patents and organizing projects to service foreign countries. The Chief Department is to support programs with the CIS. The Special Foreign Technology Division has responsibility for Wingships.

According to a recent presidential decree, the Russians would (next week) give the American Embassy a list of items where coordination with the US would be desirable. Topics include AA-11, SSN22, D-57 and many others. Captain Yetremov thinks there are some jewels in their military industrial complex. Wingship is not on the list. Probably because its not a specific name but a general category. He indicated that McDonnell Douglas will be visiting on Wingship soon. Mike said that American companies were there under their own sponsorship and did not represent the US Government. Captain Yetremov saw no limits to our cooperation.

Col Hdikayev indicated that his organization established requirements such as general configuration, equipment, and applications. Recently, they have been studying using ekranoplans for rescue at sea (oil fields). Navy has accepted some Wingships. A special department was formed to exploit wingships for special applications.

We promised names and biographies to these individuals. Mike then described the mission of the WTET.

They said that all cooperation must be overseen by the Government, through 'spets'. Capt Yetremov indicated that he has the authority to sign contracts for their Government. All the descriptions (of work?) will be distributed by this 'company'. We must deal with the Ministry of Defense (MOD).

Capt Yetremov noted that the Navy wanted to turn ownership of the Wingships over to the CHDB (Chubikov). But general headquarters interfered. So they will belong to MOD. All terms must be negotiated with MOD and Chubikov. They indicated that there may be and air show in August in Nizhny Novgorad which may feature Orlyanok - a surprise after Chubikov's comments on readiness.

Their preferred form is to create a joint wingship program to include manufacturing. They are now working on over the horizon control system to enhance Wingship safety of flight. Apparently, they want to agree on questions to be answered by their technical community. He believes that even our first phase would be delegated to his agency. If so, we need to specify our visit dates and assess the cost of the Russian efforts. He then went on to suggest cooperation on areas other than Wingship. He was

expecting a delegation from BDM Corporation the next day, and believes they want to discuss wingship.

6. June 4 - TsAGI, Moscow

We met Anotoli G. Munin (Deputy Director), Deputy Chief Sokalianski, Dr. Melts (a representative of TsAGI headquarters), and, Prof. G. Logvinovitch the head of the hydrodynamics section. We promised them a list of committee members and bios. Promised them the list of technical questions. Our comments on feasibility and certification seemed to draw smirks from this crowd. TsAGI is responsible for the Aero- and Hydrodynamics of all such vehicles done in Russia. Supports all design bureaus. They analyze all vehicle design and conduct and all experimental testing. No significant testing is done by design bureaus. All the wingships have been tested here. They also participate in full scale testing.

There is another TsAGI center in Novisibirsk, called the Siberian Science and Research Institute of Aviation. They are involved mostly in strength and structural testing. TsAGI evaluated and tested Buran (Russian Shuttle) automatic landing system. They also design space booster vehicles.

Some comments - beginning at about 100 tons, wingships need an automatic flight control system. The bigger sizes are slow to respond making them difficult to pilot. They have a computerized model of the 'Eaglet' (Orlan) and can vary parameters. It's used in a programmable moving base simulator. They've tested 150 kg models spanning about 3 meters both under automatic control and radio control. The LUN was designed for an Navy missile launching requirement. They have other concepts for future wingships. They see commercial mission as a taxi or commuter. We promised them a complete copy of our study bibliography, and a copy of our parametric study.

They have made estimates of 5000 ton wingships. They believe it will require 12 large engines of about 45 tons static thrust each for cruise. They think it will require a thrust to weight ratio of about .25 for take off. Such a craft could operate over the open sea about 80 to 85% of the time. We asked if the range-payload performance of such a craft was competitive with a modern subsonic cargo jet. They were not sure.

They said that Orlyanok was good for about 2 meter waves. This is less than 10% of its length. When queried about vehicle accident history, they indicated that most recent incidents were due to pilot error. They acknowledged earlier problems with control system (CSM), but indicated that these had been satisfactorily addressed.

7. June 6 - Moscow

Dr. Gallington departed. Mike met with RAS to discuss planning of the August WTET visit.

Attachment

October 4, 1993

MEMORANDUM FOR THE RECORD

SUBJECT: Trip Report - WINGSHIP Investigation Visit to Russia, 7-23 August 1993

FROM: Mike Francis and Roger Gallington

1. U.S. Delegation - WINGSHIP Technical Evaluation Team Visitors

Lt. Col. Mike Francis	-	ARPA
Dr. Roger Gallington	-	SAIC
Robert Wilson	-	NAWC - Carderock
C.F. Snyder	-	NAWC - Carderock
Prof. Eugene Covert	-	Massachusetts Institute of Technology
Dr. Dan Savitsky	-	Stevens Institute of Technology
Burt Rutan	-	Scaled Composites, Inc.
Joseph Gera	-	NASA Dryden FRF
John Reeves	-	NAWC - Warminster
James Camp	-	NAWC - Carderock
Hal Fluk	-	NAWC - Lakehurst
Dieter Czimmek	-	Newport News Shipbuilders
Eric Lister	-	SRS Technologies
Glenn Goodman	-	SRS Technologies
Anatoliy Shishkin	-	Russian-American Sciences
Jorge Lange	-	Russian-American Sciences

2. August 7-8 - Moscow

Team arrived in Moscow about 1700 local time. Met by various representatives of Russian American Sciences - including, Dimitri Sachkov, and Elena Kapoustina and Valentin Mathokin. Team quartered at the President Hotel, formerly Oktoberskaya (Communist Party) Hotel, Moscow.

3. August 9 - Moscow

Wingship Technical Evaluation Team (WTET) went to the Ministry of Defense for a discussion of the overall planning that had been done for our visit. Navy Captain of the First Rank (roughly equivalent to a Brigadier General) Andre Logvinenko introduced the Russians present, including Admiral Venomin Polyanskii, director of Naval Shipbuilding. Admiral Polyanskii made the first prepared comments after individual introductions. He discussed the new environment in Russia that had provided the conditions that

allowed this type of cooperation (our trip) to take place. He stated that much of the material we would discuss is considered confidential, and subject to the control of the MOD. Their support of Ekranoplan (Wingship) work began in the 60's and extended through the 70's. He indicated that they intended to share their experiences with us. They have translated and read our questions and have set an agenda that should answer most of them. He said that they intended to execute the plan as we received it today. We will see the results of their laboratory work and visit a major assembly site. He asked members of our group to share our ideas and experiences as the visit progressed. He also asked for our final response (assume he meant our final report). He said that our questions would take a long time to answer completely, but, executing this plan should result in answers to the most important ones.

Mike Francis thanked the Admiral and his staff for their hospitality and the advanced planning that they had done. He said that our charter was focused on military applications, but incorporated civil (dual use) considerations, as well. He assured the Russians that we brought technical material to share with them, including a parametric engineering analysis of this systems.

Captain Logvinenko emphasized that this was the military part of the Russian team. The Navy provided the majority support for Ekranoplan development. They had some problems in making arrangements for our visit that would satisfy all concerned. There were diverse opinions in the government community. Captain Logvinenko stated that the fact that the visit could occur at all was a victory. He emphasized that the cooperation should be two-sided. He said that our discussions would be under the supervision of security services. Any meeting outside the scheduled program would be prohibited. These rules apply during the entire two-week visit.

Admiral Polyanskii said that the approach to Ekranoplan development came from the ship community. He believed that the western approach was from the aircraft side and that comparisons could be beneficial. He saw the Ekranoplan as a multiple-purpose vehicle with its main role being a conveyor of "things". The specific application determines what those things would be. To continue this discussion of missions, Mike and Roger asked about the requirements development process that led to the present designs. Thus encouraged, Polyanskii launched into a brief history of Ekranoplan development from the Navy point of view.

Alexeyev was the leader of all significant work related to high speed water transport in the 50's. He developed the hydrofoil ships. He defined his own objectives for Ekranoplans. Competition with the other agencies influenced the direction of the work. Apparently the main competition was with the existing

Naval Aviation community. When any new technical trend develops, it automatically comes under the auspices of the MOD. In this case, the Navy was given the responsibility of directing Ekranoplan development. Concerning missions, they mentioned rescuing submarine crews and general hauling. He stated that Ekranoplans are designed for operation in heavy seas. He claimed that risk assessments are carried out on all their programs, and this was not an exception.

Mike asked if they wanted any more information on the committee. the answer was no. Then there was some time for general questions from members of the committee.

Dan Savitsky asked if other countries had expressed interest in Ekranoplans. Answer was that this is the first delegation interested in research and development. Other countries such as China and Indonesia have interest in buying existing products and have visited.

Burt Rutan asked if they had operated in the open ocean. Answer was yes, but only in short range local operations. Rutan talked about where we had seen them (in overhead photography) and asked if they had been operational there. The Admiral answered that they were built for "internal" reasons. They were purely defensive. No long range operations were planned. They saw a hospital ship mission as a possible application. 'It's basically a hauler.'

The Admiral asked what our application was. Response was that our primary focus was strategic mobility (based on the congressional direction), but that we were looking for other possibilities.

Joe Gera asked why they didn't use conventional seaplanes. The Admiral said that they preferred Ekranoplans, but gave no reason. Said that Seaplanes would be OK in some applications. Depended on the environment (believe he meant wind and waves) and the number of people to be carried. (Had the impression that he thought that Ekranoplans were larger than seaplanes and could operate in rougher conditions.)

Savitsky asked them to compare and contrast Ekranoplans and seaplanes. The Admiral said that they carried out research on both types. He believed that the amphibious Ekranoplan could be much larger than the amphibious airplane. Savitsky indicated that he saw no technical reason that would allow an amphibious Ekranoplan to be larger. Admiral said that it depended crucially on sea conditions and that the Navy had greater interest in Ekranoplans. (A major issue for our study is: which can take off and land in the roughest water.)

Mike Francis said that we were aware of some Soviet developments in the 60's and 70's. New conditions that helped trigger this study included the possibility of communicating directly with the Russians, designs from other countries, and evolving American requirements for strategic mobility.

Following the morning meeting, we re-convened in the conference room at the President Hotel. The U.S. and Russian representatives were introduced. Russian attendees included:

Academician Georgii Logvinovich	-	TsAGI
Dr. Vladimir Sokolyanskii	-	TsAGI(Dep. Director)
Capt Mikhail Malyshev	-	Ministry of Defense, Shipbuilding
Capt Nikolai Baranov	-	Russian Navy
Dr. Eugenii Fomin	-	Central Hydrofoil Design Bureau(CHDB)
Dr. Leonid Volkov	-	Krylov Shipbuilding Research Institute
Mr. Andrey Ponomarev	-	Krylov Shipbuilding Research Institute

Academician Logvinovich (TsAGI) indicated that his organization had locations both in Moscow and at the Joukowski facility. Also, within 120 km they have tow tanks capable of generating 30 to 40 meters per second model speeds. Their aero and hydro laboratories are closely related and coordinate activities.

Dr. Fomin then spoke to the group. He had expected Dr. Chubikov to be present, but noted he wasn't(reason unexplained). Chubikov had wanted to explain some more details of Ekranoplan history in Russia. Fomin indicated he would show a historical film. Their organization (Central Hydrofoil Design Bureau) traces its history to early hydrofoil development in the 40's. They became aware of the aerodynamic ground effect in the 50's. They saw a fundamental limitation of hydrofoils caused by cavitation. They estimate that cavitation limits speeds to around 60 knots with more practical values being less than about 40 knots. They sought a surface skimmer with greater speed potential. They very quickly recognized the problem of longitudinal stability. They organized a laboratory to study the WINGSHIP vehicle type. They built powered models up to seven metric tons, which attracted Navy interest. Then, in the period 1961 to 1966, they developed the so-called Caspian Sea Monster (CSM) which lifted a world record weight of 450 metric tons and approached 500 km/hr in speed. The next step was to meet a set of Navy requirements with the Orlyonuk. The LUN can gross up to 400 tons. In developing the LUN they built models up to 20 tons. They want to continue development of big Ekranoplans and do additional work to develop open ocean capability.

Roger Gallington presented the parametric results developed by Len Malthan. There was no any significant discussion on these results,.

Prof. Volkov made a presentation. He said that a key trade off on design was between stability and efficiency. He thought the efficiency would be very close to that of a good transport aircraft. He felt that the Ekranoplan must not touch the water at cruise speed. (Note that later information from the CHDB contradicted this assertion.) The aerodynamic efficiency of the aircraft type configurations is about the same as aircraft. To get superior efficiency, he suggested that the Ekranoplan must be a flying wing. The under wing blowing (PAR or Paduff) is an essential enabling technology for practical ekranoplans. He reinforced this point with the aerodynamic lift vs. speed curves for a conventional seaplane and an ekranoplan with paduff.

He suggested concentrating on smaller ships - defined to be less than 500 tons. Suggested that the competition should be motorboats and not aircraft. The idea is that the speed and efficiency of motor boats is so bad that the ekranoplan has a clear advantage. He believed that the ekranoplan would not compare favorably to a good aircraft.

4. August 10 - President Hotel, Moscow

The original plan called for the TSAGI Joukowski tour on Tuesday the 10th. Because of transportation and scheduling problems, we put that trip off until Wednesday and accomplished roughly the Wednesday agenda on Tuesday. Dr. Boris Chubikov, (Director, CHDB) joined the meeting and was introduced to everyone.

Dr. Volkov began the morning meeting with a short commentary on drag. He stated that drag was the sum of friction, wave drag, drag due to lift and spray drag.

John Reeves gave a short technical briefing on drag prediction, focusing on Lun and Orlan.

Dr. Fomin talked about applications and comparisons. He said that it is very difficult to make confident estimates of how an entirely new transportation concept, such as ekranoplan, might contribute. The possibility of new transportation means tends to cause many questions that are not central to the concept and issues that would be resolved if the new system had great promise. How good is the ekranoplan compared to other vehicles? It beats all other surface craft. It beats aircraft without airfields but not efficient subsonic aircraft operating from developed airfields. When asked if the ekranoplan could be made more efficient than modern subsonic aircraft like the 747, Airbus 330, and AN225, he said yes but only marginally. The Orlan weighs 150

metric tons or 330,000 pounds. The Lun weighs 400 metric tons or 880,000 pounds. While both of these craft are made of shipbuilding materials, future developments will be lighter. The aluminum and magnesium alloy now used is about two-thirds as strong as the duraluminum type alloys normally used in aircraft construction. They have had some internal controversy on how to estimate the total weight lifting capacity of any particular design. For example, the CSM was designed for a gross weight of 430 tons but they operated at weights up the 500 tons during the test program. Empty weight fraction should be about the same as that for highly efficient aircraft. (Apparently, the idea here is that the advantage of lower aspect ratio is offset by the necessity to design for hydrodynamic impact loads.) Fomin described the following table.

	L/D	V	V*L/D
Aircraft	15-17	800	SAME
Lun	25	500	SAME
1000T Ekranoplan (planned)	30	500	BETTER

This comparison is good for waves up to 1.5 meters high. Using the TSFC for the most efficient modern American engines only results in about a 10% improvement. There is potential for weight savings by optimizing engine for sea level performance. Existing engines are designed for high altitude. There are fundamental difficulties in designing landing gear for very large aircraft. In contrast, Ekranoplans get better with size. We should be able to design craft with gross weights from 2000 to 3000 tons. LUN operates over waves of 1.5 meter height with no degradation of performance compared to over smooth water. A large ekranoplan would have about a 5:1 weight to static thrust ratio for takeoff and a 10:1 weight to static thrust ratio for cruise. (Actual thrust at speed will be less due the thrust lapse with speed.)

Rutan asked how they handled the big thrust reduction in a design. They suggested that it's most efficient to shut down roughly half the engines in cruise. This leads to the advantages of putting some engines is the body where they can be more easily faired and prevented from windmilling and producing undesirable drag.

Rutan asked the source of Fomin's efficiency data. Fomin replied that it was from calculations and model testing. They had calculated vehicle ranges up to 10000 km.

Rutan asked what was the longest single flight. Answer was 3000 km. It wasn't quite clear if they had actually flown that for or if this was the largest estimated range of any craft they has build so far.

Fomin said that a large wingship should cruise at a height of about .1 to .15 of the chord of the wing. This is about .05 of the span for an aspect ratio of three, which seems typical.

Savitsky asked why big Wingships perform so much better. Fomin's answer was not really clear. He did say that they designed to fly 1.5 meters above the tops of the average of the one-third highest waves.

Next Dr. Chubikov made a presentation. He said that interest in ekranoplans is growing. He knows of work in other nations. Chubikov in convinced that there will be accelerating work on Ekranoplans in the future and that they will ultimately become widely used. He thought research should continue on augmenting the take-off performance and in general transportation application studies. He mentioned the need to improve current designs and remove drawbacks. He proposed international efforts, including activity directed toward fast ship (not aircraft) certification.

Dan Savitsky made a short presentation on estimates of impact loads and accelerations. He had a dialog with the Russians on wave statistics and the design criteria they used for selecting ekranoplan design cruise height.

Capt. Malyshev made a presentation on the customer's view of ekranoplans. In 1960, they prepared a report on ekranoplans for Adm. Gorshkov. They then decided to develop ekranoplans for the Navy. Various research institutes carried out research that suggested the possibility of large ekranoplans. A scope of work was identified and a size of the program defined. They also investigated possible Navy applications. The possibilities included attack, amphibious assault, and cargo. The shipbuilding institute developed the requirements. (Note here that the Russian definition of requirements apparently does not include mission performance requirements. Their definition seems to include only structural, environmental, safety, regulatory requirements, and similar things.) The shipbuilding institute had full control of research, design, etc.

Capt. Malyshev went on to give us the best explanation we have heard on mission applications. He said they had special problems in integrating weapons. The standard Navy weapons were not appropriate. They considered other high speed ship (such as hydrofoil) weapons. A major requirement was that one of the craft be amphibious. This requirement led to the Orlyonuk. Paduff was there primarily for the amphibious capability. The design featured a front loading door. The Lun is not amphibious and was designed for another application. It did meet Navy requirements in local operations. Missile launching from the "back" of the Lun was difficult. The installation was poorly integrated resulting in very high drag. They did fire (salvo) missiles while flying at

500 km/hr with no negative consequences. The ship was "pushed down" a small amount and only momentarily. There was no rolling motion. They are planning out-of-ground-effect (OGE) flights for the Lun. Operationally, OGE flight would be used only to ferry the craft over land to different theaters or operational areas and to launch weapons from altitudes that might be more appropriate for the weapon or for the mission. He stated that the craft was relatively hard to detect. They have made an effort to avoid bad (for radar) observability in the design. (Don't understand this. It appears that the wing-fuselage junction and the propulsion wing-fuselage junction are nearly corner reflectors!) His discussion on IR detectability was more sensible. He said that operating in the earth's turbulent boundary layer tended to dissipate the warm air making the wake less detectable by IR. He indicated that the Wingship was a most effective means for conducting anti-submarine warfare (ASW). They have had a lot of experience using the wingship to search for subs, and it is very effective. The area searched per unit time is better than any other craft. They use hydro acoustic and non acoustic methods. Another mission they consider to be very promising is rescuing complete crews of ships (especially subs) in an emergency. The Lun can carry a complete sub crew. The sketch shows the general arrangement of a test they have done in sea state four (see Figure 1). The wingship points into the wind an wave naturally because of the large vertical tail. The area behind the wing is relatively sheltered, and the trailing edge forms a beach for beaching small boats and swimmers. Their studies show that one wingship is not enough. There needs to be three ships for each theatre of operations to provide adequate coverage and robustness of the system. He suggested that they are designing a new wingship specifically for the rescue mission, presumably the modified Lun which we observed under construction at the Volga plant.

This work has ben financed for 30 years by the Navy. It has been very expensive! The magnitude was about the same as their investment in stealth technologies. More than millions of dollars. (Infer that this means in the billions.) For the programs to continue, they need outside cooperation. They have no orders yet.

Bob Wilson gave a short presentation on the Power Augmented Landing Craft (PARLAC) research work at (then) David Taylor Center (DTRC). He described experimenting with the angle of the engines to achieve good performance and said that it was critical. The maximum weight of their vehicle was 2700 pounds and the measured gross static thrust was 400 pounds for a maximum weight-to-thrust ratio of 6.5. They achieved speeds of 55 mph. The height of the bottom of the wing above the water was about 12 inches.

A. V. Ponomarev discussed their ideas for future cooperation in wingship technology. Concerning longitudinal stability, he felt that it was essential for certification. They have had some success in solving this problem. They understand longitudinal stability in ground effect cruise fairly well. The more interesting and difficult problems are related to the take-off, especially just as the craft leaves the water in waves. This phenomena is called "planing off" in seaplane jargon. Blowing under the wing tends to move the center of pressure aft. Finally, longitudinal stability out of ground effect and in the transitions between IGE and OGE needs more work.He believes there should be cooperative work on the science and techniques associated with altitude control in ground effect flight.

Cooperative efforts in improving test facilities and in exploiting the capabilities of existing facilities could be productive. They would be pleased to do testing in their facilities on a cooperative program.

In response to a question, he discussed the how he would go about developing a 5000 ton wingship. They have built a 600 ton hovercraft and a 1000 ton SES. He thought they would have to work out a number of technology areas to be able to confidently design a 5000 ton wingship. Materials and structures technology are not presently adequate for the application and would need lots of development. He encouraged a step by step process. He would use vehicles of the LUN size for model testing.

His specific suggestion was to have the US help them finish testing the existing LUN in a joint testing program. The craft is already well instrumented. He imagined a joint testing program followed by a series of models leading to the larger craft. However, his personal enthusiasm was for smaller craft that he felt would have more commercial value. He believes that a five-to-one scale up is weight was a practical limit. That would mean that the next large construction could be no larger than 2000 tons. He also proposed cooperative efforts in marketing and selling.

Professor Kirill Rozhdestvensky, Head of Mathematics Department, St. Petersburg Marine Technical University, gave an outstanding lecture on the application of asymptotic methods to the WIG problem. He generalized the Barrows-Widnall results, and was able to use the physics of the problem to show why a particular characteristic length was important for each aspect of the solution. Because his methods required the angle of attack be much smaller than h/c, eg, the angle of attack is less than a degree, if one uses Volkov's value for optimum h/c. Thus the results did not have much application to the WIG as they used it. Still and all, this was part of their effort and thus relevant.

5. August 11 - TsAGI, Joukowski facility / location

TsAGI Deputy Director, Leonid Shkadov welcomed us and gave us an introduction to TsAGI. Moscow facility director Anatoli Munin and his deputy, Vladimir Sokolianskii were introduced. TSAGI was formed in 1918 in Moscow. The first director was Joukowski. Chaplygin led TSAGI from 1921 and was director for many years. Tupolev worked at TSAGI and initiated the new site. The host city has a population of about 100,000.

The new site was started in the 30's and was mostly finished before the war. T-100 is the designation of their large subsonic wind tunnel with a test section of 24x15 meters. It can accept models with spans of up to 15 meters. T-104 is a propulsion wind tunnel. T-106 was there first transonic wind tunnel. All of these were completed prior to the war. T-109 is a supersonic tunnel and is ten years old. T-128 is a very modern transonic tunnel with automatic porosity adjustment of the test section walls. That tunnel is technically significant and is currently under contract to Boeing for testing. T-117 is a hypersonic tunnel capable of Mach numbers to twenty. They also have facilities for structural testing including strength, strain, and fatigue. In addition, they have an anechoic chamber for acoustic fatigue, and solar vacuum facilities.

One of TsAGI's functions is to test aircraft for the design bureaus. They have capable simulators to test control systems. They have a vertical wind tunnel for rotorcraft tests. They also have hydrodynamic test facilities. The overall site covers about 150 'hectares'. It includes a central power plant and compressor station. They coordinate with design bureaus on aerodynamic features of all designs. TsAGI is the state expert on aircraft. They issue all clearances and certifications of new aircraft. The manpower is about 10,000. They separated flight research as a separate topic in the 40's. They are now the clearance authority for all the Wingships.

Academician Logvinovich then discussed some of their hydrodynamic work especially relevant to Wingships. They have cooperated with the Beriev Design Bureau on both seaplanes and Wingships. Typical seaplane design grosses 80 metric tons and cruises at 750 km/hr. The take off speed would be about 180 km/hr which would require testing in water to 200 km/hr. Wingships have unique hydrodynamic problems which are more interrelated than seaplanes. They do coordinated testing in different facilities.

Their big low speed towing tank provides speeds to 16 m/sec. It can be fitted with a wavey surface on the bottom to simulate flight across waves. In this kind of testing the model Wingship is actually under water. It provides high Reynolds number with a small model at low speed. For more conventional testing, they

generally Froude scale in this facility. Froude scaling in this size range does not give correct spray patterns or separation. These features are usually obtained from special large scale tests. Then corrective flow devices are placed on the smaller models to get the correct spray and separation. The higher speed towing tank, which can reach 40 m/sec can achieve the correct separation and spray patterns. They also use motor boats and tow models from a long arm extending out to the side. Radis control models are another technique which they used specifically on the Bartini Wingships.

One of the very practical reasons for Wingships to have OGE capability is maneuverability. In wings-level flight in strong ground effect they are basically straight line machines. The OGE capability gives them maneuverability and results in a practical overall design.

Logvinovich said that to have any chance of achieving a lift over drag ratio of 35 would require a $C_{DO} < 0.01$ based on wing area. On some large craft they have experienced impact loads of 40 tons, and they have tried to work out ways to estimate and limit the damage caused by impacts. The Paduff really helps in this regard, and he showed some fundamental data showing the effect of paduff on the accelerations caused by water impacting the flat lower surface of the wing. He believes that very large Wingships would be practical. They would not be amphibious and would require the development of significant infrastructure.

The aeroservoelastic problem was discussed by another TsAGI expert. He said that were significant differences between airplanes, seaplanes, and Wingships. He worked out the special requirements for the various unusual vehicle types. There were some comments on the crashes generally indicating that they were pilot error and did not result from technical deficiencies of the craft.

At day's end, the WTET held a caucus. Rutan suggested that we gather a minimal set of data on each of their large machines. Specifically we would ask for:

(1) The mission requirement in terms of range, speed, payload, and sea conditions.

(2) Actual achieved performance.

(3) Maximum flight weight and bollard thrust.

(4) Date of last flight.

(5) Vehicle disposition (crashed, worn out, cannibalized, etc.)

(6) Picture - photo preferred.

(7) Total planform area.

(8) Empty weight fraction.

Other items discussed at the caucus included: (1) most important questions for the Russians by Wilson, Savitsky, and Camp; (2) suggestions for itinerary modifications; (3) C_{D0} reduction test program and high Mach Ekranoplan wing sections by Reeves; and (4) evaluation, options, and finding a positive answer by Fluk.

6. August 12 - President Hotel, Moscow

We reconvened to hear from the people from Beriev Design Bureau at Taganrog. Valintin N. Kravtsov introduced the team. Dr. Khiril Rozhdestvensky continued his discussion of insights gained through extensive application of singular perturbation methods to the aerodynamics of wings in ground effect.

Shortly after the morning break, we (Mike Francis and Roger Gallington) were called out of the meeting to go the Russian White House to meet with the Russian Parliament. In the event, we didn't meet with the whole parliament, but one member and a staff expert. We spoke with Alexander Piskunov, Co-Chairman of the Committee on Defense and Security (their HASC). He is primarily responsible for the defense part of that committee. After the perfunctory introductions, Mr. Piskunov described the situation in Russia. In the process of reducing the size of their military activities, they cannot just dump millions of servicemen on an economy that already has problems coming up with new jobs. He also intimated concerns about instability. Therefore, they have chosen to maintain the welfare of a large number of servicemen and their families at the expense of weapons procurement and, especially, research and development. To keep their capable technology centers from falling apart, they must find outside markets for some of these products and get contracts or other arrangements with outside customers for research and development work. Because our visit had some possibility of leading to a cooperative Russian and American program, he had interest in it. But his interest was much broader. He referred to an agreement between the major western countries to prohibit transferring certain kinds of technology to Russia (COCOM). Piskunov stated his belief that many of the technologies on the list should not be restricted (Apple computers, for example), and that these restrictions hinder Russia in its efforts to get its economy working in harmony with the rest of the world. He asked our support in getting the restrictions lifted. He introduced in a leading figure in Russian telecommunications technology, and suggested that this was an area of mutual benefit. It was a very

cordial meeting lasting less than an hour. Mike and Roger returned to the hotel to attend afternoon sessions.

The majority of the presentations in the afternoon were provided by the Beriev people. They thought that they could get better performance from a seaplane than a Wingship. However, they indicated a desires to cooperate in the design of a Wingship, if that's what the customer really wanted. In the very large sizes, they would use ground effect to assist in the take off run, but not for cruise. It was not clear what particular features of ground effect they valued for take off. It could have been the paduff or the reduction in induced drag. It seems unlikely that they would have any use for the increase in lift caused by ground effect because more lift is available with conventional high lift devices out of ground effect.

Dr. Volkov gave a short tutorial contrasting ground effect features discernable from a lifting line perspective vice those from a 2-D airfoil perspective. He made the point that, for typical aspect ratios, the enhancement in lift due to ground effect as a result of the lifting line phenomena was much greater than that due to the 2-D phenomena. Increasing the aspect ratio reduces the increase in lift due to ground effect and makes is more difficult to develop good longitudinal stability. He also said that they have computer models of the motion of a wingship after impulsive loads. The air under the wing cushions the impacts.

There was a short discussion of the last Orlyonuk accident. As a result of pilot action, the craft left ground effect. The pilot did not add enough power for a proper recovery. The craft came back to the water and struck in a slightly nose-down attitude. It's not clear whether or not the craft ever stalled or just flew one cycle of a 'phugoid' mode oscillation. It skipped off the water again and then hit the second time hard enough to break it. Someone asked whether or not a wave impact could have caused the crash. The answer was no. In answer to a related question, it was stated that the main purpose of the hydroski was to damp overloads during landing.

7. August 13 - Moscow

A small group within the WTET (Mike Francis, Roger Gallington, Burt Rutan, Gene Covert, Joe Gera and Eric Lister) visited the Yakovlev Design Bureau in Moscow. The remaining team members went on a cultural excursion to Zagorsk.

At Yakovlev, we were greeted by Chairman Alexander Dondukov, Deputy Chairman Arcady Gurtovoy, Chief Designer Nicholas Dolzhenkov, and Deputy Chief Designer Konstantin Popovich. The company is currently becoming privatized. They will be owned by a

combination of the employees and the state in a specified ratio. Deputy Chief Gurtovoy indicated that they recently hosted NASA and the U.S. Marine Corps who had an interest in the YAK-141, a VTOL aircraft. They build the only Russian commercial aircraft type that is certified for passenger use on international routes. It's the YAK-40&42 family. They have sold the YAK-40 to Italy and FRG. They are working with the airworthiness certification in Canada, UK, and the US. The airworthiness requirements are different. The product line includes aircraft ranging in size from small sport aircraft to those carrying up to 170 passengers.

One of their current design projects is the YAK-UTK trainer. They designed it in response to a 1991 Russian Air Force RFP. They competed with the other Russian design bureaus. They presented their preliminary designs to the Air Force. They were selected for a second phase with two competitors. A winner may be announced next year. The program is nearly dormant because of the reduction in military spending in Russia, so Yak is looking for western partners to keep the design going. They are teamed with Aeromacchi, an Italian company with experience in training aircraft, and are building a prototype for demonstrations in 1994. Some detail design data were provided.

They made the point that high alpha training is important. A Russian avionics company makes the flight control system. This trainer is beyond the US JPATS. It's an advanced trainer. They do not think supersonic capability is important. They don't think that spins and tail slides are important in the advanced trainer for more sophisticated machines. The design has special ducts at the top to provide FOD-free air for ground running. The winglets improve cruise L/D by about 10% without hurting the maneuverability (roll rate?) of the airplane. The airplane can serve as its own simulator to train pilots. There is software to diagnose training flights. They are using our GPS for navigation and a dedicated system of their own for approach and landing. They can simulate dropping bombs and other weapons. There are hard points designed into the wings. They measure angle of attack from the pressure distribution around the nose.

They discussed the development of the YAK 141. Development of the YAK 138 (the 141's predecessor) was started in 1960-61 roughly parallel to the Harrier. The take-off weight is nine metric tons. The lift thrust is provided by two engines of 5700 kg thrust each. Roll control is by tip jets. They were required to use in-country engines for the design. They made 200 YAK 138s. The vertical lift engines had a life of about 450 hours. They operated at gross weights from 8.5 tons to 11.5 tons. The 138 had a mechanical flight control system. Its top speed was 1100km/hr. The possible normal acceleration ranged from -3 to +7 g's. The YAK 141 was developed from 1980 to 1989. The customer wasn't happy with the 138 and sought a better design. They wanted a

truly supersonic design for ground attack and point defense. The maximum speed in 1800 m/sec at altitudes of 5 km and above. The maximum Mach number is 1.8. The top speed at sea level is 1250 km/hr. The maximum weight for vertical take off is 15800 kg, and the maximum weight for short take off is 19500 kg. It can operate to a radius of 690 km carrying a 2-ton payload. To do a program like this, they get a block of money and hold out a management reserve.

The was first deployed only on ships because they had deck surfaces that could stand the heat. They can use concrete ramps for a while, but they eventually fail. They did consider other arrangements, such a combined lift and cruise engines. They agree that combined lift cruise engines would result in a lighter design with less frontal area. However, they were driven by tradition and experience to the dedicated engines. Their lift engines have a thrust to weight ratio of 12:1.

8. August 14 - 15 Moscow / Nizhny Novgorod

We traveled to Nizhny Novgorod on Saturday evening and arrived Sunday morning. CHDB personnel met us with a bus at the train station and took us to the hotel. Several coordination meetings were held. We attended a military airshow held over the city's Volga river area. MiG 29 and Mig 31 aircraft were among the many vehicles to perform.

9. August 16 - Central Hydrofoil Design Bureau, Nizhny Novgorod

The meeting convened in the central auditorium of the CHDB. Admiral Polanskii, who came from Moscow for the first day, emphasized that they had assembled people from all over Russia to demonstrate their comprehensive coverage of the Ekranoplan subject. The CHDB, on this site, has a long history of technical accomplishment.

Dr. Chubikov indicated that all of the large wingships were built here. He acknowledged the highly respected status of our delegation and said that his team was similarly well qualified and carefully selected. He believed the community needed to develop a new vision of sea transport. He believes that take off weights of 2000- 3000 tons were technically feasible. He claimed to have several proposals for cooperation but was not specific. He said that his agency intended to continue developing wingships. He introduced his team.

Mike Francis introduced the U.S. team and described it as neither critic nor advocate. Said that our team wanted to give the wingship the best possible chance, and that we've come to appreciate its potential in many applications. Our study has two parts -- technology and missions. We are scheduled to make our

report by November and intend to begin Phase II immediately after approval is granted. We are also looking for areas of cooperation.

Dr. Chubikov introduced CHDB work. Alexeyev initiated the whole effort, and is personally responsible for Russia's emphasis on hydrofoils and wingships. They have built 30% of the world's hydrofoils. (learned from other sources that Russia has built more hydrofoil boats than any other country.) They have sold hydrofoils to many countries -- 35 to Greece alone. They built 600 of the Raketa (Rocket) hydrofoils over a period of 30 years as well. The newer Meteor carries 120 passengers, and they have built it for 30 years as well. All together they have built 1500 hydrofoil ships. They indicated that they have also built 6000 smaller hydrofoil boats. They gave one to Mr. Nixon. They now have three hydrofoils in development. The gas turbine powered Cyclone will carry 250 passengers at 45 knots. The diesel powered Olympia is to be used on a run from Paris to Stockholm. On its delivery run from the Black Sea to Estonia, it operated in 3.5 meter waves without damage. They have built two or three air cavity boats. These have both passenger and cargo applications.

The Wingship development has involved research from multiple research institutes. The Russian Navy received an early report on their progress on Wingships, and that's what initiated their big program. They have recently initiated work on passenger craft. They have designs which carry from five to eight people, designs around 150, and designs to accommodate 250 people. They are prepared to cooperate on passenger wingships. Large wingships are more efficient.

Concerning the development path, Chubikov indicated that one can go by gradual stages or by leaps. Alexeyev was right to do the 500 ton CSM early. It defined the most important problems early in the program. Chubikov believes that the optimum take off weight now would be somewhere between 1000 and 3000 tons. All their data and foreign studies indicate an optimum in this range. CHDB has had good experience up to 500 tons. They overcame major problems. They solved the dynamics problem at all speeds. They have an adequate approach to propulsion in the marine environment. They have make fully welded aircraft like structures. Their main aspiration is to raise the efficiency.

He indicated that there are several new problems to be addressed, including more research into applications and marketing. They should build two to four machines in the range five to five thousand tons. They should continue to press for a way to certify the craft internationally.

We then made an attempt at a group session of questions and answers. The format involved the WTET members addressing

questions to the current Lun designer, who was supported by his staff. The Lun designer personally answered all the questions.

Gene Covert:
Q: Where is fuel carried in the Lun?
A: In the wings. A small amount in the tail.
Q: Is your welded aluminum as strong as tempered aluminum?
A: Just used weldable material so far. Close to having a high strength weldable alloy.

Czimmek:
Q: Do you relieve manufacturing stresses?
A: (No response.)

Wilson:
Q: What are the main design loads; high speed impact or sea sitting?
A: High speed landing loads.

Rutan:
Q: What is the highest speed for landing?
A: Can survive landing and take off in 3.5 meter waves. Can touch the water at 450 km/hr.

Covert:
Q: What is the maximum landing weight?
A: 80% of the take off weight.

Rutan:
Q: What is the maximum speed for full flaps?
A: Approximately 350 km/hr

Reeves:
Q: What is the limiting Mach number?
A: The flutter speed in 120 km/hr above 500 km/hr.
Q: How many engines are in operation in cruise?
A: All are on. In an emergency they can cruise on any four engines.

Savitsky:
Q: Describe the individual impact requirements at take off and landing.
A: The first touching of the water during landing does not drive the design. Subsequent impacts do. The hydroski helps. The main structure touches at 270 km/hr.
Q: How much loading (g's) do you experience on the hydroski?
A: About two g's.
Q: What does the hydroski weigh?
A: (No response.)

Covert:

Q: What is the wing limit load?
A: It is designed for seaworthiness.
Q: Is it designed for strength or fatigue?
A: It is designed for both strength and fatigue.

Gera:
Q: Does the craft operate at or near a constant angle of attack?
A: Yes. Height depends on speed and thrust.
Q: What are the functions of the auto controls?
A: (None or not recorded.)

Czimmek:
Q: What are your safety factors?
A: Use aviation type safety factors that are different for each component. They range from 1.2 to 2.

Gera:
Q: Is it naturally stable?
A: Yes. Auto control system provides additional damping of some modes.

Wilson:
Q: Is it stable both in-gram-effect and out-of-ground-effect?
A: Yes.

Rutan:
Q: Where is the c.g.? What is the c.g. range?
A: Wouldn't answer. The c.g. range is small but adequate. Major quantity of fuel is located on the c.g.

Covert:
Q: Does it employ a wet wing?
A: Yes.

Covert:
Q: Are there limber holes?
A: Yes.
Q: Any stress corrosion problems in fuel tanks?
A: No.
Fluk:
Q: What payload and range did you design for?
A: Classified.

Gera:
Q: What was the cause of the last crash?
A: Pilot error.

Savitsky:
Q: To what extent is salt a problem?
A: Worked with engine specialists to get solutions.
Q: How many hours between washes?

A: Wash engines on every flight on some installations. In one case, once a year.

Fluk:
Q: How many take offs and landings before an engine change?
A: Use just service life, not cycles. They are military engines. Use them about 700 to 1000 hours.

Reeves:
Q: Why didn't you use turboprops?
A: We do use them on some designs.

Fluk:
Q: Have you considered a long life commercial aircraft engine?
A: Now working on this problem.

Covert:
Q: What is rate of normal acceleration increase with elevator angle and cruise speed?
A: Not relevant for ground effect flight.

Rutan:
Q: What is the elevator activity in turbulence and waves?
A: Less than 5 deg.
Q: What elevator displacement is required for takeoff?
A: 20 deg each way at different times during take off.
Q: What is the maximum flap deflection?
A: 20 deg.
Q: Are the flaps used deferentially as ailerons?
A: Yes. And there is some aileron control left at the maximum flap deflection.

Francis:
Q: Has the Lun been flight tested at altitude?
A: Not yet. We're working on it.

Camp:
Q: What is the longest flight?
A: 2000 km in about 4 hours.

Rutan:
Q: Earlier craft had a vertical fin apparently to generate lateral forces for turning. Why did you delete it?
A: It was inefficient.

Fluk:
Q: What is the ferry range?
A: Don't know. (Not used for this purpose.)

Rutan:
Q: What is the turning radius?

A: (No response.)

10. Tuesday, August 17, Chkalovsk Test Site

We were transported via hydrofoil boat to the test site near Chkalovsk. The trip took about two hours. Individual conversations during the trip yielded several nuggets of new information.

Dan Savitsky learned that they use a load of 3.5 g's plus a safety factor of 1.8 to establish yield limits. (Len Malthan should use a similar factor in his parametrics.) Hydroski weight is typically 4-6% of gross weight. Eric Lister had a good interaction with their propulsion specialist and got most of the information he required.

The group witnessed demonstration flights of both two place 'Strizh' trainer wingship and the Volga II air cushion vehicle. The Strizh performed for a short time, but demonstrated maneuvering flight under both in-ground effect and out-of-ground effect conditions. Flights were conducted on the Gorky Sea, which we observed from several hydrofoil boats and a catamaran (group members dispersed). Photos were taken.

We returned to Nizhny Novgorod via hydrofoil that evening. We convened a short caucus of the technical team after dinner. The general perception was that we weren't getting some of the information we needed to understand the Russian technology. A major concern was the absence of any real hard data - especially flight test data. This would be a focus of much continuing discussion. We also decided that a serious problem was that the individuals that possessed the information we sought were not getting an opportunity to speak. Therefore, we decided to force the next session to be in smaller groups organized into topical areas where we needed the most help. The topical areas turned out to be: (1)missions and applications; (2) flight test; (3) structures, seaworthiness, and materials; and (4) design. Mike conveyed our request forcefully to RAS and the Russian government representatives.

11. Wednesday, August 18, the Kremlin, Nizhny Novgorod.

The meeting started with a presentation by Mr. Sokolov, the designer of the Orlyonuk. He described the Russian history in ekranoplan development as a three phase program. The initial goal was to beat the performance of hydrofoils. They saw an absolute limit on the speed of hydrofoils at about 60 knots, due to cavitation. Since this was only marginally above the speeds they had already achieved, a new technical approach was required.

During the 60's, there were both theoretical and experimental studies, including tests with vehicles ranging from 1.5 to 2 tons. They tried to learn the appropriate scaling rules and how to achieve stability near the surface. Sokolov presented a chart showing Froude number on the horizontal axis and power required per unit weight on the vertical axis. One then observes three 'regimes' as you progress from lower left to the upper right. First is pure air cushion craft. In the middle are hybrid air cushion (Volga II) type craft. At the upper right corner is the Strizh type vehicle (pure Ekranoplan). The Ekranoplan has evolved to a configuration that uses paduff to take off and a hydroski for landing. The amount of blowing and the relative size of the hydroski is specialized for each craft.

Sokolov gave a brief history of the developments leading up the CSM. He has been continuously in the business for thirty years -- since leaving the University. These include:

1961 CM1	2.3 ton vehicle
1962 CM2	3.2 ton.vehicle
1963 CM277	6.3 ton vehicle
1962 CM3	3.4 ton vehicle
1964 CM4	4.8 ton vehicle
1964 CM5	7.37 ton vehicle
1965 CM8	8.1 ton vehicle
1967 VT1	0.7 ton vehicle
1966 CSM	500 ton vehicle

Sokolov then gave a description of their wingship design process separated into structures, layout, controls and instruments and his vision for future designs.

On structures, they initially used TSAGI data and recommendations. From that they developed the strength requirements. They tested several models, varying both Froude and Reynolds numbers to establish requirements. They correlated data with the CSM. Considered both dynamic loads and fatigue.

Their design sequence is to: (1) choose the layout first; (2) find the optimum wing loading (apparently based on a speed requirement and a knowledge of the lift coefficient for good stability IGE) and; (3) find the stability foci as a function of height, angle of attack, aspect ratio, and end plate depth. They would also investigate efficiency in PAR effect. The available payload mass was determined last.

They have had some problems with automatic controls. All wingships have static and dynamic stability. The Volga II stays in strong ground effect and is naturally stable. The Strizh is more maneuverable and is stable both IGE and OGE. Only the Lun and Orlyonuk have (artificial) damping and stabilization.

They have had to make some compromises to operate in the sea environment that detracted from performance. They use an aluminum and magnesium alloy which has about 2/3 the strength of high strength aluminum alloys. In future designs they would propose to use new alloys of their own or to use US alloys. Examples are lithium and scandium alloys with aluminum. They used aviation engines modified for the marine environment. They would expect some improvement in engine performance with a special purpose design. They believe that to achieve adequate safety in flight control that they need a robust height measurement.

Till now, they have been designing only for military requirements. They are now trying to meet requirements for civil operation. They want to improve the max L/D. It's now 25, and they seek 30. The hydroski now has an L/D of only 5 to 7, and they would like to go higher. They recognize the need to get the empty weight down.

Sokolov described three size ranges of ekranoplans. All require a static thrust to weight ratio of about 0.25. Up to 500 tons, he believes the airplane configuration is best. Around 1000 tons, he believes the flying wing configuration is best. They originally had design concepts from 1000 tons to 5000 tons that would be nuclear powered. The latest design concept has evolved to the chemically powered craft in the 300 ton range.

They now believe that the practical limit for the number of engines is 10. Since new engines are rated at about 40 tons, they see a 2000 ton limit based on engine technology alone. However, Sokolov felt that was too large a jump from the present 350 ton size and recommended an 800 ton design as the next logical step. The 800 ton machine would be a flying wing or a multiple wing configuration. The high L/D they sought (took this to be 25 or 30) would be for smooth water only. In sea state 4 or 5 (3.5 meter waves), this would degrade to 20 or 25. He thought all applications studies from now on must be dual purpose. Sokolov appeared to like the idea of designing craft to meet a requirement, as opposed to just making something and seeing what it does.

Dr. Diomidov of the Central Research and Development Institute, "Elektropribor", St. Petersburg, reviewed the efforts they had made on the development of automatic controls. In 1964, they built the two-person AN-25 which cruised at 130 to 140 km/hr. They made 42 flights in it. He personally flew it with Alexeyev. In 1967, they flew the CSM which had instruments to guide the pilot, but (to our understanding) no automatic control system. In 1974, they first flew the Orlyonuk which has a flight control system (Smerna 4 is designation). In 1986, they flew the Lun which has a newer version flight control system designation - Smerna 3). There have been a total of 1500 hours of trouble free

operation of the Orlyonuk and Lun flight control systems. They first considered the autopilot as just an add-on. Its specific purpose was to reduce the pressure on the pilot during night operations. They did not manage to build a large ekranoplan that had satisfactory natural stability. They decided that they must have automatic flight controls.

They divide the problem into several general areas. The system must damp the vehicle motion about all three rotational axes. It must establish the proper trim condition for each speed of flight. It must assure speed stability. In the cockpit, the system must provide appropriate angle limit warnings to the pilot. It must provide means for the pilot to trim the controls. It must provide for control of the engines and provide appropriate switchology and fault detection. They achieve reliability by hardware redundancy, equipment redundancy, signal mixing and selection, and appropriate rate and displacement limits. They use equipment from the aviation design bureaus.

Special control system problems peculiar to ekranoplans are: (1) wave height measurement; (2) navigation; (4) demanding angular rate limits; and (5) control surface overloads. They must stabilize pitch angle within a very narrow angular range. Typical aircraft type control requirements are not appropriate.

Turning is unique. It requires the operation of all controls and combines sideslip and bank. The rule is to maintain the clearance at the inside wingtip. Therefore, the pilot must know what this clearance is. First they did it with a rear view mirror. Later they used direct measurements of the tip clearance. Diomidov noted that no accidents were ever attributed to an FCS failure.

The CHDB intends to employ this institute for all future designs of FCS systems. All systems have been delivered on time. There have been no flight test holds attributed to FCS. The systems provided effective damping and improved stability. The systems made it possible to stabilize the craft at otherwise unstable parts of the envelope to achieve better L/D.

Among new things they would do on the next FCS are: (1) control large scale vertical maneuvers; (2) automate the take off and landing runs; and (3) optimally allocate functions between manual and automatic. Diomidov made the point that flight control work should start early in the design process. He also mentioned that they used a simulator in their FCS development work -- although none of our group saw it.

We then broke up into small specialty discussion groups. Some comments from the 'design' and the 'applications' groups follow. Other group comments can be found in the appended trip reports.

-Design Group notes-

John Reeves began by noting that different design groups in Russia seem to favor different configurations. Irkutsk is associated with the flying wing. Taganrog (specifically Bartini) was associated with a combined planform with high aspect ratio and low aspect ratio parts.

In response, Sokolov noted that the CHDB settled on the low aspect ratio aircraft type configuration at least partly to get good behavior over waves. For example, they made extensive studies of the tandem wing configurations and found that they were too closely coupled to the surface in pitch. This coupling caused a number of accidents and crashes (in models, presumably). They concluded that the tandem configurations were only useful in a very narrow altitude range.

However, Sokolov believes that at very large sizes the airplane configuration becomes less desirable. At 800 tons, he believes the craft should be a spanloader or flying wing. He definitely wants a tailless version over 600 tons. The reduced tail area will help the L/D a lot. He believes that careful shaping of the wing will result in adequate stability. He agrees that the hydrodynamic features such as steps and spray strips are major drag producers but didn't make any specific suggestions on how to reduce this drag.

Roger Gallington then discussed the typical western systems engineering approach of first developing requirements and then designing to them and asked Sokolov what items should be included in a top level set of requirements. The minimum list came out to be: (1) payload description; (2) range; (3) height of waves; (4) loading and unloading infrastructure; (5) take off and landing distances; (6) gust conditions; and (7) basing. We then asked him to fill in this table for the existing craft and for what he thought he could design in the future.

REQUIREMENT	EXISTING TECHNOLOGY		NEW TECHNOLOGY	
Payload	80 ton	80 ton	150 ton	500 ton
Range (km)	2000	2000	5000	12000
Wave Height (m)	3	3	3.5	4.5-5
Loading	Dock	Dock	Dock	Dock
Turn Rad (km)	4	3.5	5	10
TO Dist/Time	1.5m/3.5km	90s/3.5km	2m/5km	5km
Basing	Optional	Optimal	Sea	Sea
Cruise (km/hr)	400	400	450-500	600
TOGW (mtrc tns)	350	250-280	800	2000

Sokolov said they had several problems they had to work on to make better craft. He thought the L/D and the speeds they could achieve would be economically attractive. They need better

engines with lower fuel consumption. The empty weight fractions must get better. They must keep the cost lower than an aircraft that can perform the same mission.

They can safely clip the tops of the waves in sea states three to four. (He could have meant wave heights in meters.) They use full elevator control for takeoff and landing. They limit available elevator travel in cruise. Pilots must be trained for ekranoplan operation. Human factors are very important above 450 km/hr. Similar on all vehicles. Must get the pilot help. He believes that a flying wing design could be all near the surface -- that is, it may not require an OGE part to stabilize it.

Concerning de-icing, he said that the inlet lips were hot, the leading edge of the wing is taken care of by the paduff, and the rest of the craft requires a dedicated deicing system. In big designs it may be most practical to use a Diesel engine for low speed maneuvering. Such an engine could use the same fuel type as the turbine engines.

Existing wingship designs did not incorporate all advantages. The first designs satisfied mainly tactical requirements and did not emphasized either efficiency or cost. There were always competition with the aircraft community approach to designing to the same requirements. There were positive aspects of this competition. They could find quite a bit of aircraft type equipment that they could qualify for wingship applications. Additionally, since the wingship environments were, in some ways, less demanding than aircraft requirements, they could find some non-aviation equipment that they could qualify.

The applications group discussed the following mission/applications areas (all were mentioned as being of interest to the Russians):

- Sea rescue under adverse marine conditions.
- Passenger transport over 'unique' routes.
- Changing crews on oil rigs / fishing boats.
- Urgent transport of outsized cargo.
- Travel in Siberia
- Natural resource extraction in shallow water environs.

A prepositioned worldwide 'fire department' made up of Orlan wingships transported in the backs of large 'Mariah" (Antonov) aircraft was discussed at length. Five units, properly positioned, could adequately cover the globe, it was argued. Could be used for rescue, oil slick containment, or other emergencies.

A unique transportation route between Vladivostsk and Japan was mentioned by Capt Malyshev. Other candidate South Pacific routes

were also discussed. Chubikov mentioned that the Wingship was not attractive (efficient) for transatlantic operations.

We took the train back to Moscow on Wednesday evening.

12. Thursday, August 19, TsAGI, Moscow facility.

A small group of us visited the TsAGI location in Moscow. Our objectives were the simulator and the hydrodynamic testing facilities. Roger joined the hydrodynamics group. Mike joined the simulator group. Our tour included two wind tunnels and one towing tank.

TsAGI/Moscow employs 850 people in four major departments. They are: (1) low speed aerodynamics; (2) aviation acoustics; (3) hydrodynamics; and (4) scientific information services. The scientific information services department services the whole aviation industry -- not just TsAGI.

They do research on ekraloplans as a class as opposed to the Nizhny Novgorod facility which models specific craft. They strive for static and dynamic stability and make recommendations to the designers which they can accept or reject. They only make recommendations for flight procedures IGE. They are the clearance authority for OGE flight. They clear every flight of the Orlyonuk and Lun. They believe that a 1200 ton design could achieve the same efficiency as a good subsonic aircraft but not much more. It would have to be loaded and fueled at docks. It would be for commercial operations. Here are some estimated technical characteristics:

Flying Height= 5 meters
Payload = 400 tons
Range = 6000 km
L/D = 26-30
W/S = 600 kg/m^2

Before 1990, there was both shipbuilder and aviation activity in the program. When they started contemplating OGE ferry flights for weather avoidance, the Navy realized that is was essentially an aircraft and had to be handled that way.

They also do most of the model testing for seaplanes. In fact, they have been involved with seaplanes longer than they have wingships. Wingships have some peculiarities. For example, they can almost completely model seaplanes by adding aerodynamic, hydrodynamic, and propulsion forces. They have not been able to made a similar model for wingships because of the strong interactions of these effects near the surface. The paduff complicates the situation even more. Also, the wingships tend to have many complicated and interacting hydrodynamic features. A

seaplane hull has a maximum L/D (at its worst speed) of about four to five. The corresponding value for a wingship with paduff is about six to seven. The flaps blow back under hydrodynamic loads in all their large designs. They have found that, if the beam of the model hull is greater than 300mm, Reynolds effects are negligible for Froude scaled models.

TsAGI efforts in flight controls has extended back 25 years. Research has taken multiple paths focusing on 3 'methods' of control - yaw, roll and pitch angle. Two Ekranoplan modes were mentioned - the so-called 'quick motion' mode (not a true short period mode) - 4-5 seconds time constant; and a much longer 'slow motion' mode. A special height control measurement instrument was devised to aid automatic system in coping with quick motion mode effects. A classified radio-isotope altitude sensor was mentioned, but not discussed.

13. Friday, August 20 - Monday, August 23

The technical team departed for the U.S. during this period. Lt. Col. Francis conducted several meetings with government officials during this period, including VAdm. Polyanskii, M/G Miranov, Capt. Logvinenko and Dr. Degtaryev.

Attachments: Trip Reports (8)

ADVANCED RESEARCH PROJECTS AGENCY
3701 NORTH FAIRFAX DRIVE
ARLINGTON, VA 22203-1714

23 November 1993

MEMORANDUM FOR THE RECORD

SUBJECT: Trip Report, Moscow/Makhachkala, Russia 25 September - 3 October 1993

FROM: LtCol Michael S. Francis (ARPA) and Dr. Roger Gallington(SAIC)

1. We arrived in Moscow on the evening of 25 September 1993 and remained overnight in Moscow on Saturday (25 September 1993) and Sunday evenings. During that time, the team assembled. Wingship Technical Evaluation Team (WTET) members involved included ourselves, as well as Burt Rutan, Joe Gera, Steve Hooker and Jim Camp. Representing contractors (at their own expense) were Charles Miller and Ed Parrott from Lockheed and Frank Tubbesing from McDonnell Douglas Corporation.

2. <u>Monday, 27 September 1993</u>.

We traveled with our three interpreters and Anatoliy Shishkin (all from Russian American Sciences) via chartered bus to Moscow's Vnukovo airport and boarded an Aeroflot flight for Makhachkala in Dagestan.

Upon arrival, everyone exchanged introductions and greetings. We then had a short introductory meeting at the hotel. The Governor of Dagestan spoke first. He said that he had recently traveled to the United States to seek opportunities for scientific cooperation. Dr. Boris Chubikov then gave some of the essential features of the Wing-in-Ground (WIG) effect program in Russia. All the large WIGs were built in Nizhny Novgorod. All (including the CSM, Orlyonok, and LUN) were tested here on the Caspian Sea. There were two important test sites -- one at the nearby town of Kaspisk and another on Cheken island. He emphasized that their team had only a very short time to prepare for the upcoming demonstration. The Orlyonok really should have been given a total overhaul. It is nearly at the end of its useful life. Because the changes in the former Soviet Union have caused some deterioration of conditions in the outlying republics, preparations for the demonstration required even more time than they originally expected. But everything was in place, and Chubikov expected to complete the demonstration by lunchtime on Tuesday (28 September 1993). He went on to say that unstructured discussions between Russian and American specialists were permitted. He closed with the comment that he thought the WIG idea was worthy of a joint effort. The meeting then closed abruptly, and all substantial planning activities were deferred to unspecified later planning sessions of smaller groups.

Several smaller discussions ensued. Dr. Roger Gallington joined the propulsion discussion. Gregory Perevozkin (who had had extensive conversations with Eric Lister during our last trip) was very interested in what the American technologists thought about propelling large WIG vehicles. Since Eric wasn't there, Roger informed him that we were using the estimated sea-level performance of the new turbofans under development. Mr. Perevozbin went on to make a series of points with respect to propulsion. He based many of his observations on a NASA-sponsored engine studies done by the American engine companies. The study was called E-cubed. A key

result of the NASA study was that there was an optimum turbine inlet temperature that minimized the sum of costs, considering fuel and other direct operating costs along with additional construction and repair costs associated with the higher turbine inlet temperatures. According to the General Electric (GE) part of this study, the optimum value was about 1550 deg Kelvin. He went on to say that the variation in this parameter caused by salt deposition was larger at higher mean values. Therefore, he observed that hotter engines are less conservative in the salty environment. The main effect of salt deposition appears to be to lower the flow rate through the compressor. The second order effect is to lower the compressor efficiency. In propulsion terms, the salt deposition moves the whole compressor map to the left. He made the observation that the Pratt and Whitney engines we are using for our parametrics have a high turbine inlet temperature and would not be good for this application. (However, Roger believes that if a lower turbine inlet temperature were used, we would predict less range for our parametricly analyzed vehicle.) Mr. Perevozkin further reminded us that the Russians had spent a lot of time coming up with a practical engine wash system. Other comments include:

- the equipment usually used on the hydrofoil boats and other marine gas turbine applications is not practical, it is too heavy and voluminous.
- they need lots of access for inspection.
- a flight recorder preserves engine data.

Mr. Bulanov who designed the smaller Strizh vehicle described it with the following table of values.

Table I - STRIZH Data

Power	= Two 160 hp piston engines
Weight	= 1.6 metric tons
Top Speed	= 200 km/hr
Cruise Speed	= 170 km/hr
Max Height Waves for Takeoff	= .6 to .7m
Max Height Waves for Cruise	= 1.5m

TAKE OFF SCHEDULE

Speed (km/hr)	Thrust Angle (deg)	Flap Angle (deg)	Power Level (%)
0	25	10	100
50-60	25	20	100
90	25	30	100
110-120	0	30	100
170	0	0	60

Bulanov was deputy to Alexeyev on the Caspian Sea Monster (CSM). He indicated that they had lifted approximately 544 metric tons in 1973.

There were some questions on the wing section of the Strizh. Notes indicate a thickness ratio of about 10% located at about 30% chord.

In a meeting later that evening, Capt. Maleshev said that they had done studies that showed we could have done the Persian Gulf job at one-fifth the cost using wingships vs. C-130s. Mike commented that we would have to compare to C-5s and C-17s.

At that meeting, we also passed on our requests for data and other information to be gathered from the demonstration. The next two lists itemize our request. The third list in section three is a quantitative narrative of the flight provided by Dr. Sokolov, which partially responds to these data requests.

Data Requested from Flight Recorder

As a function of time and for each maneuver:

1. Indications of thrust or power for each engine including: pressure ratio, rotational speed, and torque
2. Airspeed
3. Altitude
4. Normal acceleration, lateral acceleration
5. Fuel Flow Rate
6. Heading
7. Pitch and Bank (Angles, Rates)
8. Nozzle Position
9. Flap Position
10. Rudder, Elevator, Aileron Positions

Specific Data or Maneuvers Requested for Review/Observation

1. Take-off Weight
2. Enter the cockpit and make a sketch and take a picture of the instruments and controls
3. Brief the CHDB photographer on what to do during various phases of the demonstration (NOTE: We will ask the camera man to photograph the critical instruments during various phases of flight. We will probably want him to photograph the horizon during the control pulses.)
4. Accompany the crew on the pre-flight check (2 or 3 of our team)
5. Engine start
6. Taxi to water
7. Maneuver at very low speed
8. Take off (Normal)
9. Fly the race track pattern in ground effect
10. Fly steadily at three different speeds at the same height
11. Make a maximum rate turn through 90° of heading change. (We want to view from inside the turn).
12. With autopilot on:
    a. make a pitch pulse (view this from side)

b. make a roll pulse (would like to view from rear)

c. make a yaw pulse (would like to view from rear)

13. Land
14. Shut down engines
15. Take off with full flap deflection from rest or about 10 km/hr
16. Landing (a second time)
17. Exit water onto ramp
18. Maneuver into position and shut down.
19. Learn the final weight.

Lengthy discusions concerning our entry onto the base also ensued. Concerns were raised about late security restrictions being imposed. Capt (Col) Andre Logvinenko, Mike's Russian counterpart, spent much of the evening trying to deal with the security issues.

3. Tuesday, 28 September 1993.

The team was transported to the Russian Naval Base and Kaspisk at 9:00am. Entry was provided without incident, although security was heavy. We were told then we were the first foreigners (of any nationality) ever allowed in the area.

Photography was restricted to the Orlyonok vehicle being demonstrated. Photos at the Lun vehicle and other portions of the facility were not permited. We were permitted to photograph the Orlyonok during preflight preparations as well as during the flight at length. Many photographs were taken. Events were recorded on four separate videorecorders (Rutan, Hooker, Miller, and Tubbesing). A composite video of the flight events has been made and is available.

The actual flying took place over an approximate two hour period. Significant events included: engine run-up, ocean entry, taxi, takeoff (in rough seas), cruise flight - single pass, 90° turn, out-of-ground effect flight, landing, taxi, and exit from water onto ramp.

Immediately following the flight, we were informed that - contrary to prior statements - we would not be allowed to enter the vehicle and that actual flying recorder data would not be provided. LtCol Francis strenuously objected but to no avail. Detailed discussions were held with Russian designers and operators to gather as much useful data as possible. To partially answer our questions, Dr. Sokolov provided the following written description of the flight.

Wingship Demonstration Flight Held 09/28/93.

1. Takeoff weight of the wingship - about 120 tons.
2. Rough sea, wave height 1.5-2.0 meters (plus a windwave and choppy sea) the wave is higher than the regular by 0.5 m
3. Wingship characteristics

   3.1 Beginning of movement:

   - starting and cruising engine are in the takeoff mode with a total thrust of 35 tons; the cruising engine 15 tons the starting engines 10.5 tons.

- the nozzles of the starting engine are in horizontal position i.e. the engines work to produce thrust (without blowing under the wing)
- the flaps are retracted
- the hydroskis are extracted and are in the starting position (that is 20-60% of the full extraction and the full extraction is 1.5 meters (depending on the sea state).

3.2 When the wingship reaches the speed 50 - 70 km/hr the nozzles are brought to an angle of +15° with blowing under the wing.

3.3 When the wingship reaches the speed of 150-180 km/hr the flaps are gradually extended to the +20° position.

3.4 At the speed of 200-230 km/hr the takeoff from the water surface occurs, and when the speed reaches more than 250 km/hr the position of the nozzles becomes horizontal, the flaps are gradually retracted and the wingship is accelerated to a cruising speed of 360-380 km/hr.

3.5 When the cruising speed has been reached the starting engines usually are shut down, and the cruising engine works in the mode that is about 0.85 of the nominal one.

3.6 During the cruising mode:

- flight altitude is 0.5 - 1.0 m (up to 3 meters), depending on the sea state.
- flaps are retracted
- the pitch is 0° - 1°
- the roll is 0°

3.7 The fuel consumption in the cruising mode is about 3.0 tons per one hour of flight.

3.8 When performing a turn (R = 2.5 - 5.0 km) the thrust of the cruising engine is increased and the altitude is increased up to 3.0 - 4.0 meters. The roll is 5° - 10° (15°) and the wingship performs a coordinated turn with the flaps working in the aileron mode.

3.9 When landing the thrust of the cruising engine is changed, the flaps are extended to +30°, the altitude of the flight is 3.0 - 4.0 m, the hydroskis are in landing mode position, (that is they are fully extended), and the pitch is slightly increased.

3.10 The speed when the hydrosk touch the water is ~250 km/h

3.11 When the wingship is decelerating the flaps are retracted (so that they won't get damaged when touching the water), and during the taxiing (160-170 km/h) the blowing under the wing is switched on, (the nose engines are switched on before the landing), but during the demonstration flight, due to its brevity and due to the sea state, they weren't shut off during the flight at all.

3.12 The calculated vertical acceleration at the takeoff - landing mode is about 5-6 g units - side acceleration (the calculated (or the regular) one is about 1.5-2.0 g units.

For the demonstration flight, the pressure loads on the hull and the wings during takeoff and landing were considerably lower than the design limits would have allowed.

****

After the flight (about 1500 hours), there was a general meeting at which Capt. Maleshev suggested a general question and answer period. One of our hosts from Dagastan invited the team for a meeting with the Mayor of Kaspisk during the afternoon of the 29th, to be followed by a dinner on the shore of the Caspian sea. Dr. Chubikov said that the flight was over waves near the limit of the capability of the vehicle -- he called it "near emergency" conditions. Said the waves were 2.25 meters high. The general question period began. Most of the discussion was with the test pilot.

The transition from land to sea was normal. The conditions were quite bad with wind driven chop on top of a rolling sea. Today the waves ranged from 1.9 to 2.5 meters during the takeoff. The long wavelength of the rolling sea was bad. They came very close to getting water in the engines. The take off was normal. The waves can cause significant impacts and the pilot adjusts the extension of the hydroski as appropriate. On this takeoff, the hydroski was extended farther than normal. After the takeoff, the flight was routine. The pilot hand-flew the entire flight. The pilot had not had much recent practice and took this opportunity to get some. At the roughest point, the sea was up to three meters and the average clearance was four meters. The air injection engines were left on during the flight because the flight was short and they did not want to introduce the uncertainty of starting them for landing. One of the main uses of the forward engines is to lift the nose to keep the water from getting into the engines. The turn radius of 2.5 to 3 km at 370 km/hr. On landing the ski first touches the water at 230 km/hr. Someone asked if the craft could be trimmed to fly "hands off" in the conditions that existed today. He answered that, under smoother conditions, it will fly unattended without autopilot, but today conditions were too rough for that. It has trim controls for all three axes. It will fly out of ground effect at 340 km/hr on the same amount of power that produces 360 km/hr in ground effect. Speed range out of ground effect is 250 to 400 km/hr. The take off weight was about 120 metric tons, and the landing weight was about 117 metric tons. The pilot looks in a rear view mirror to see if any water goes into the cruise engine. He also looks at the water just forward of the wing leading edge to help decide how to deflect the forward nozzles. Cruise requires about 85% of the rated power of the cruise engine.

4. <u>Wednesday, 29 September 1993</u>.

LtCol Francis left for Moscow in the morning. He was required to return to the United States earlier than the rest of the group to attend other meetings. Dr. Gallington was put in charge of the US delegation for the remainder of the trip.

Here are a few notes from the meeting with the Vice Mayor of Kaspisk and the Chairwoman of their city council. The mayor had gone to Moscow for political discussions. There was some ceremonial toasting and gift giving first.

Kaspisk is much larger than we had believed. Population 300,000, if our notes are correct. It has a museum and cultural center for each of 38 languages. Located just north of the Caucasus mountains the town is inhabited by many small groups speaking different languages. They have a University of Foreign Relations with many foreign students. It is relatively new "city of revolutionaries", defined and built after the Bolshevik revolution. Since there was no Kapisk until the communists came and westerners were not allowed to visit until recently, we were the first Americans in the town of Kaspisk. The Caspian Sea has changed over time. In the 19th century there was no land at the present location of Kaspisk. When the Communists came to power, they had many programs in the town's Lenin Square to encourage people to support the Supreme Soviet. This developed constructive movements uniting to improve Dagastan. There are seven major political units. There are many ethnic groups including mountain jews, moslems and others. The groups have tended to merge and intermarry. The area experienced its last earthquake in 1970, a severe tremor.

5. We returned to Moscow on Thursday (30 September 1993), traveling most of the day.

6. **Friday, 1 October 1993.**

Steve Hooker and Roger met with Academician Logvinovich (TsAGI) to discuss the problem of understanding the air injection phenomenon from a more fundamental basis. They discussed several points including "matching" the cross section of the incoming jet to get a sudden pressure rise at the wing leading edge.

Professor Logvinovich continued to make the point that he preferred the flying wing configuration for a very large WIG. However, he thought air injection was required for take off and landing. He admitted the forward-extending pylons would be required to carry the air injection engines. He believes that using only hydrodynamic planing surfaces for support during takeoff will always cause unacceptable drag. We mentioned the obvious problem of getting the center of gravity in the right place with the forward-mounted engines and no tail. There was no obvious answer. He recognizes that the means of loading payload or boarding passengers is an important design requirement. He believes it should be towed into port and unloaded with conventional cranes. It should be treated like a ship in the harbor and maneuvered with tugs. Professor Logvinovich recommended a book he had written and which had been translated into english. We have since obtained a copy.

7. **Saturday, 1 October 1993.**

Most of the team left Moscow on Saturday evening. The parliament building (their white house) was shelled on Sunday morning, as Yeltsin's troops attempted to end the rebellion.

DATE: 08-25-93

TO: WIG File

FROM: R. Gallington

SUBJECT: Trip Report - Russia 08-07 through 08-21

Arrive in Moscow about 1700 local time. Met by Representatives from Russian American Sciences - namely, Dimitri Sachkov and Elena Kapoustina. Dimitri drove me to the President Hotel.

On 08-09, the whole Wingship Technical Evaluation Team (WTET) went by charter bus to the Ministry of Defense for a discussion of the overall planning that had been done for our visit. Navy Captain of the First Rank (roughly equivalent to a Brigadier General) Andre Logvinenko introduced the Russians present including Admiral Polyanski. Admiral Polyanski made the first prepared comments.

He discussed the new environment in Russia that had provided the conditions that allowed this type of cooperation (our trip) to take place. He stated that much of the material we would be discussed is confidential. It is subject to the control of the MOD. Their support of Ekranoplan work began in the 60's and extended through the 70's. They intend to share their experiences with us. They have translated and read our questions and have set an agenda that should answer most of them. He said that they intended to execute the plan as we received it today. We will see the results of their laboratory work and visit a major assembly site. He asked members of our group to share our ideas and experiences as the visit progressed. He asked for our final response. (I assume he meant our final report.) He said that our questions would take a long time to answer completely. But, executing this plan should result in answers to the most important ones.

Mike Francis thanked the Admiral and his staff for their hospitality and the advanced planning that they had done. He said that our charter included both civil and military applications. He assured the Russians that we brought technical material to share with them to indicate what progress we had made on our study so far and some information on related work in the United States.

Captain Logvinenko emphasized that this was the military part of the Russian team. The Navy provided the majority support for Ekranoplan development. They had some problems in making arrangements for our visit that would satisfy all concerned. There were diverse opinions in their community. Captain Logvinenko stated that the fact that the visit could occur at all was a victory. He emphasized that the cooperation should be two-sided. He said that our discussions would be under the supervision of security services. Any meeting outside the scheduled program will be prohibited. These rules apply during the entire two-week visit.

Admiral Polyanskii said that the approach to Ekranoplan development was from the ship community. He believed that the western approach was from the aircraft side and that comparisons could be beneficial. He saw the Ekranoplan as a multiple-purpose vehicle with its main role being a hauler of things. The application determines what those things would be.

To continue this discussion of missions, Mike and Roger asked about the requirements development process that led to the present designs. Thus encouraged, Polyanskii launched into a brief history of Ekranoplan development from the Navy point of view.

Alexeyev was the leader of all significant work related to high speed water transport in the 50's. He developed the hydrofoil ships. He defined his own objectives for Ekranoplans. Competition with the other agencies influenced the direction of the work. Apparently the main competition was with the existing Naval Aviation community. When any new technical trend develops, it automatically becomes under the MOD. In this case, the Navy got the responsibility of directing Ekranoplan development. Concerning missions, they mentioned rescuing submarine crews and general hauling. He stated that Ekranoplans are designed for operation in heavy seas. He claimed that risk assessments are carried out on all their programs, and this was not an exception.

Mike asked if they wanted any more information on the committee. the answer was no. Then there was some time for general questions from members of the committee.

Dan Savitsky asked if other countries had expressed interest in Ekranoplans. Answer was that this is the first delegation interested in research and development. Other countries such as China and Indonesia have interest in buying existing products and have visited.

Burt Rutan asked if they had operated in the open ocean. Answer was yes but only in short range local operations. Rutan talked about where we had seen them (in overhead photography) and asked if they had been operational there. The Admiral answered that they were built for "internal" reasons. They were purely defensive. No long range operations were planned. They saw a hospital ship mission as a possible application. It's basically a hauler.

The Admiral asked what our application was. Someone answered that our primary focus was the strategic mobility (based on the congressional direction) but that we were looking for other possibilities.

Joe Gera asked why they didn't use conventional seaplanes. The Admiral said that they preferred Ekranoplans but gave no reason. Said that Seaplanes would be OK in some applications. Depended on the environment (I believe he meant wind and waves) and the number of people to be carried. (I had the impression that he thought that Ekranoplans were larger than seaplanes and could operate in rougher conditions.)

Savitsky them to compare and contrast Ekranoplans and seaplanes. The Admiral said that they carried out research on both types. He believed that the amphibious Ekranoplan could be much

larger than the amphibious airplane. Savitsky indicated that he saw no technical reason that would allow an amphibious Ekranoplan to be larger. Admiral said that it depended crucially on sea conditions and that the Navy had greater interest in Ekranoplans. (A big question for our study is: which can take off and land in the roughest water. We need some sort of a graphic in the final report addressing this point.)

Logvinenko made some comment I didn't record.

Mike Francis said that we were aware of some Soviet developments in the 60's and 70's. The new conditions that triggered this study were the possibility of communicating directly with the Russians, other examples of designs from other countries, and evolving American requirements for strategic mobility.

Somewhere along here we ended the meeting at MOD had lunch and re-convened in the conference room at the President Hotel.

Academician Logvinovich said the TsAGI had locations in Moscow and at the Joukowski lab. Within 120 km they have tow tanks capable of 30 to 40 meters per second. Their aero and hydro laboratories are closely related and coordinate their activities.

Other people introduced included Sokilyanskii, Capt. Malyshev, Dr. Fomin, Volkov, and Ponomarev. The WTET was also there.

Dr. Fomin spoke to the group. He had expected Dr. Chubikov to be there but he wasn't. They new he flew to Moscow, but for some reason he didn't get to the meeting. He had wanted to explain some more details of Ekranoplan history in Russia. Fomin indicated he would show a historical film. The organization (Central Hydrofoil Design Bureau) traces its history to early hydrofoil development in the 40's. They became aware of the aerodynamic ground effect in the 50's. They saw a fundamental limitation of hydrofoils caused by cavitation. They estimate that cavitation limits speeds to around 60 knots with more practical values being less than about 40 knots. They sought a surface skimmer with greater speed potential. They very quickly recognized the problem of longitudinal stability. They organized a laboratory to study the WIG vehicle type. They built powered models up to seven metric tons. That attracted Navy interest. Then in the period 1961 to 1966 they developed the CSM which lifted a world record weight of 450 metric tons and approach 500 km/hr. The next step was to meet a set of Navy requirements with the Orlyonuk. The LUN can gross up to 400 tons. In developing the LUN they built models up to 20 tons. They want to continue development of big Ekranoplans and do additional work to develop open ocean capability.

Somewhere along in here, Gallington presented the parametric results developed by Len Malthan. There wasn't any significant discussion.

Prof. Volkov made a presentation. He said that a key trade off on design was between stability and efficiency. He thought the efficiency would be very close to that of a good transport

aircraft. He felt that the Ekranoplan must not touch the water at cruise speed. (Note that later information from the CHDB contradicted this assertion.) The aerodynamic efficiency of the aircraft type configurations is about the same as aircraft. To get superior efficiency the Ekranoplan must be a flying wing. The under wing blowing (PAR or Paduff) is an essential enabling technology for practical ekranoplans. He reinforced this point with the aerodynamic lift vs. speed curves for a conventional seaplane and an ekranoplan with paduff.

He suggested concentrating on smaller ships - defined to be less than 500 tons. Suggested that the competition should be motorboats and not aircraft. The idea is that the speed and efficiency of motor boats is so bad that the ekranoplan has a clear advantage. He believed that the ekranoplan would not compare favorably to a good aircraft.

The original plan called for the TSAGI Jukovsky tour on Tuesday the 10th. Because of transportation and scheduling problems we put that trip off until Wednesday and accomplished roughly the Wednesday agenda on Tuesday.

Dr. Chubikov joined the party on the 10th and was introduced to everyone.

John Reeves went through some technical material.

Dr. Fomin talked about applications and comparisons. He said that it is very difficult to make confident estimates of how a entirely new transportation means, such as ekranoplans may contribute. The possibility of new transportation means tends to cause many questions that are not central to the concept and issues that would be resolved if the new system had great promise. How good is the ekranoplan compared to other vehicles? It beats all other surface craft. It beats aircraft without airfields but not efficient subsonic aircraft operating from developed airfields. When asked if the ekranoplan could be made more efficient than modern subsonic aircraft like the 747, A330, and ANT225, he said yes but only marginally. The Orly weighs 150 metric tons or 330,000 pounds. The LUN weighs 400 metric tons or 880,000 pounds. Both of these craft are made of shipbuilding materials, Future developments will be lighter. The aluminum and magnesium alloy now used is about two-thirds as strong as the durauminum type alloys normally used in aircraft construction. They have had some internal controversy on how to estimate the total weight lifting capacity of any particular design. For example, the CSM was designed for a gross weight of 430 tons but they operated at weights up the 500 tons during the test program. They picked up more than they originally thought possible. Empty weight fraction should be about the same as that for highly efficient aircraft. (Apparently, the idea here is that the advantage of lower aspect ratio is offset by the necessity to design for hydrodynamic impact loads.) Fomin described the following table.

	L/D	V	V*L/D
Aircraft	15-17	800	SAME
LUN	25	500	SAME
1000T Ekrano	30	500	BETTER

This comparison is good for waves up to 1.5 meters high. Using the TSFC for the most efficient modern American engines only results in about a 10% improvement. There is potential for weight savings by optimizing engine for sea level performance. Existing engines are designed for high altitude. There are fundamental difficulties in designing landing gear for very large aircraft. In contrast, Ekranoplans get better with size. We should be able to design craft with gross weights from 2000 to 3000 tons. LUN operates over waves of 1.5 meter height with no degradation of performance compared to over smooth water. A large ekranoplan would have about a 5:1 weight to static thrust ratio for takeoff and a 10:1 weight to static thrust ratio for cruise. (Actual thrust at speed will be less due the thrust lapse with speed.)

Rutan asked how they handled the big thrust reduction in a design. They suggested that it's most efficient to shut down roughly half the engines in cruise. This leads to the advantages of putting some engines is the body where they can be more easily faired and prevented from windmilling and producing undesirable drag.

Rutan asked the source of Fomin's efficiency data. Fomin replied that it was from calculations and model testing. They had calculated vehicle ranges up to 10000 km.

Rutan asked what was the longest single flight. Answer was 3000 km. It wasn't quite clear if they had actually flown that for or if this was the largest estimated range of any craft they has build so far.

Fomin said that a large wingship should cruise at a height of about .1 to .15 of the chord of the wing. This is about .05 of the span for an aspect ratio of three, which seems typical.

Savitsky asked why big wigs perform so much better. Fomin's answer was not really clear. He did say that they designed to fly 1.5 meters above the tops of the average of the one-third highest waves.

Next Chubikov made a presentation. He said that interest in ekranoplans is growing. He knows of work in other nations. Chubikov in convinced that there will be accelerating work on Ekranoplans in the future and that they will ultimately become widely used. He thought research should continue on augmenting the take-off performance and in general transportation application studies.

Mike Francis made some comments or had a dialog with Chubikov which I did not record.

Dan Savitsky made a short presentation on estimates of impact loads and accelerations. He had a dialog with the Russians on wave statistics and the design criteria they used for selecting ekranoplan design cruise height.

Capt. Malyshev, from Krylov, made a presentation on the customer's view of ekranoplans. In 1960 they prepared a report on ekranoplans for Adm. Gorskhov. They then decided to develop ekranoplans for the Navy. Various research institutes carried out research that indicated the

possibility of large ekranoplans. A scope of work was identified and a size of the program defined. They also investigated possible Navy applications. The possibilities included attack, amphibious assault, and cargo. The shipbuilding institute developed the requirements. (I note here that, the Russian definition of requirements apparently does not included mission performance requirements. Their definition seems to include only structural, environmental, safety, regulatory requirements, and similar things.) The shipbuilding institute had full control of research, design, etc.

Capt. Malyshev went on to give us the best explanation we have heard on mission applications. He said they had special problems in integrating weapons. The standard Navy weapons were not appropriate. They considered other high speed ship (such as hydrofoil) weapons. A major requirement was that one of the craft be amphibious. This requirement led to the Orlyonuk. Paduff was there primarily for the amphibious capability. The design featured a front loading door. The LUN is not amphibious and was designed for another application. It did meet Navy requirements in local operations. Missile launching from the back of the LUN was difficult. The installation was poorly integrated resulting in very high drag. They did fire (salvo) missiles while flying at 500 km/hr. Nothing bad happened. It just pushed the ship down a small amount and only momentarily. There was no rolling motion. They are planning out of ground effect flights for the LUN. Operationally, OGE flight would be used only to ferry the craft over land to different theaters or operational areas and to launch weapons from altitudes that might be more appropriate for the weapon of for the mission. He stated that the craft was relatively hard to detect. They have made an effort to avoid bad (for radar observability) in the design. (I don't understand this. It appears that the wing-fuselage junction and the propulsion wing-fuselage junction are nearly corner reflectors!) His discussion on IR detectability was more sensible. He said that operating in the earths turbulent boundary layer tended to dissipate the warm air making the wake less detectable by IR. They have had a lot of experience using the wingship to search for subs, and it is very effective. The area searched per unit time is better than any other craft. They use hydro acoustic and non acoustic methods. Another mission they consider to be very promising is rescuing complete crews of ships (especially subs) in an emergency. The LUN can carry a complete sub crew. The sketch show the general arrangement of a test they have done in sea state four. The wingship points into the wind an wave naturally because of the large vertical tail. The area behind the wing is relatively sheltered, and the trailing edge forms a beach for beaching small boats and swimmers. Their studies show that one wingship is not enough. There needs to be three ships for each theatre of operations to provide adequate coverage and robustness of the system. They are designing a new wingship specifically for the rescue mission. (Is it based on the LUN, or is it completely new?).

This work has ben financed for 30 years by the Navy. It has been very expensive! The magnitude was about the same as their investment in stealth technologies. More than millions of dollars. (I infer that this means in the billions.) For the programs to continue, they need outside cooperation. They have no orders yet.

Bob Wilson gave a short presentation on the Power Augmented Landing Craft (PARLAC)

research work at (then) DTRC. He described experimenting with the angle of the engines to get good performance and said that it was critical. The maximum weight was 2700 pounds and the measured gross static thrust was 400 pounds for a maximum weight-to-thrust ratio of 6.5. They achieved speeds of 55 mph. The height of the bottom of the wing above the water was about 12 inches.

A. V. Ponomarev talked about their ideas for future cooperation and related that to wingship technology. He proposed cooperative efforts in marketing and selling.

Concerning longitudinal stability, he felt that it was essential for certification. They have had some success in solving this problem. They understand longitudinal stability in ground effect cruise fairly well. The more interesting and difficult problems are related to the take-off, especially just as the craft leaves the water in waves. This phenomena is called "planing off" in seaplane jargon. Blowing under the wing tends to move the center of pressure aft. Finally, longitudinal stability out of ground effect and in the transitions between IGE and OGE needs more work.He believes there should be cooperative work on the science and techniques associated with altitude control in ground effect flight.

Cooperative efforts in improving test facilities and in exploiting the capabilities of existing facilities could be productive. They would be pleased to do testing in their facilities on a cooperative program.

In response to a question, he discussed the how he would go about developing a 5000 ton wingship. They have built a 600 ton hovercraft and a 1000 ton SES. He thought they would have to work out a number of technology areas to be able to confidently design a 5000 ton wingship. Materials and structures technology are not presently adequate for the application and would need lots of development. He encouraged a step by step process. He would use vehicles of the LUN size for model testing.

His specific suggestion was to have the US help them finish testing the existing LUN in a joint testing program. The craft is already well instrumented. He imagined a joint testing program followed by a series of models leading to the larger craft.

However, his personal enthusiasm was for smaller craft that he felt would have more commercial value. He believes that a five-to-one scale up is weight was a practical limit. That would mean that the next large construction could be no larger than 2000 tons.

On 08-11, we toured the TSAGI facilities at the Joukowski location. Deputy head Monin gave the introduction. TSAGI started in 1918 in Moscow. The first director was Joukouski. Chaplygin led TSAGI from 1921 and was director for many years. Tupolev worked at TSAGI and initiated the new site. The host city has a population of about 100,000.

The new site was started in the 30's and was mostly finished before the war. T-100 is their large subsonic wind tunnel with a test section of 24x15 meters. It can accept models with spans

of up to 15 meters. T-104 is a propulsion wind tunnel. T-106 was there first transonic wind tunnel. All of these were completed prior to the war. T-109 is a supersonic tunnel and is ten years old. T-128 is a very modern transonic tunnel with automatic porosity adjustment of the test section walls. That tunnel is technically significant and currently has contracts with Boeing for testing. T-117 is a hypersonic tunnel capable of Mach numbers to twenty. They also have facilities for structural testing including strength, strain, and fatigue. They have and anechoic chamber for acoustic fatigue, and solar vacuum facilities.

One of TSAGI's functions is to test aircraft for the design bureaus. They have capable simulators to test control systems. They have a vertical wind tunnel for rotorcraft tests. They have hydrodynamic test facilities. The reservation is covers about 150 hectares. It includes a central power plant and compressor station. They coordinate with design bureaus on aerodynamic features of all designs. TSAGI is the state expert on aircraft. They issue all clearances and certifications of new aircraft. The manpower is about 10,000. They separated flight research as a separate topic in the 40's. They are the clearance authority for all the wigs.

Academician Logvonovich then discussed some of their hydrodynamic work especially relevant to wigs. They have cooperated with the Beriev Design Bureau on both seaplanes and wigs. Typical seaplane design grosses 80 metric tons and cruises at 750 km/hr. The take off speed would be about 180 km/hr which would require testing to 200 km/hr. Wigs have unique hydrodynamic problems with more interrelated effects than seaplanes. They do coordinated testing in different facilities.

Their big low speed towing tank provides speeds to 16 m/sec. It can be fitted with a wavey surface on the bottom to simulate flight across waves. In this kind of testing the model wig is actually under water. It provides high Reynolds number with a small model at low speed. For more conventional testing, they generally Froude scale in this facility. Froude scaling in this size range does not give correct spray patterns or separation. These features are usually gotten from special larger scale tests. Then corrective flow devices are placed on the smaller models to get the correct spray and separation.

The higher speed towing tank, which can reach 40 m/sec gets the separation and spray patterns right. They also use motor boats and tow models from a long arm extending out to the side. R/C models are another technique which they used specifically on the Bartini wigs.

One of the very practical reasons for wigs to have OGE capability is maneuverability. In wings-level flight in strong ground effect they are basically straight line machines. The OGE capability gives them maneuverability and results in a practical overall design.

Logvonovich said that to have any chance of achieving a lift over drag ratio of 35 would require a cee dee zero of less than .01 based on wing area. On some large craft they have experienced impact loads of 40 tons, and they have tried to work out ways to estimate and limit the damage caused by impacts. The PADUFF really helps in this regard, and he showed some fundamental data showing the effect of paduff on the accelerations caused by water impacting the flat lower

surface of the wing.

He believes that very large wigs would be practical. They would not be amphibious and would require the development of significant infrastructure.

Another guy (didn't get his name) discussed the aeroservoelastic problem. He said that were significant differences between airplanes, seaplanes, and wigs. He worked out the special requirements for the various unusual vehicle types.

There were some comments on the crashes generally indicating that they were pilot error and did not result from technical deficiencies of the craft.

The WTET had a caucus. Rutan suggested that we gather a minimal set of data on each of their large machines. Specifically we would ask for:

1. The mission requirement in terms of range, speed, payload, and sea conditions.

2. Actual achieved performance.

3. Maximum flight weight and bollard thrust.

4. Date of last flight.

5. Disposition (crashed, worn out, cannibalized, etc.)

6. Picture

7. Total planform area.

8. Empty weight fraction.

Other items discussed at the caucus included: (1) most important questions for the Russians by Wilson, Savitsky, and Camp; (2) suggestions for itinerary modifications; (3) cee dee zero reduction test program and high Mach Ekranoplan wing sections by Reeves; and (4) evaluation, options, and finding a positive answer by Fluk.

On 08-12 we reconvened in the President Hotel to hear from the people from Tagnarog - the Beriev design bureau. Valintin N. Kravtsov introduced the team from Tagnarog. Rozhdestvensky gave a presentation on the most important insights he had gained through extensive application of singular perturbation methods to the aerodynamics of wings in ground effect. Shortly after the morning break, Mike Francis and I were called out of the meeting to go the Russian White House to meet with the Russian Parliament.

In the event, we didn't meet the whole parliament but just one member and one of his staff. We

spoke with Alexander Alexandrovich. He is a deputy chairman of the Committee on Defense and Security. He is primarily responsible for the defense part of that committee. The chairman (or other deputy) is probable a former official (possibly the head) of the KGB. After the perfunctory introductions, Alexander got to the point. In the process of reducing the size of their military activities, could not just dump millions of servicemen on an economy that already has problems coming up with new jobs. Therefore, they have chosen to maintain the welfare of a large number of servicemen and their families at the expense of weapons procurement and research and development. To keep their capable technology centers from falling apart they must find outside markets for some of these products and get contracts or other arrangements with outside customers for research and development work. Because our visit had some possibility of leading to a cooperative Russian and American program he had some interest in it. But his main interest was much broader.

There is an agreement between the major western countries to prohibit transferring certain kinds of technology to Russia. I think it's called the COCOM agreement, or something like that. Some big Japanese company got into trouble a couple of years ago by letting some ship propeller manufacturing technology out. Alexander (and presumably Russian government) believes that many of the technologies on the list should not be restricted (Apple computers, for example) and that these restrictions hinder Russia in its efforts to get its economy working in harmony with the rest of the world. I got the impression that this issue is so important to them that they routinely ask any westerner who they think might be influential on this matter in to discuss it with them. It was a very cordial meeting lasting less than an hour.

We returned to the meeting after the majority of the presentations from the Beriev people. They thought that they could get better performance from a seaplane than a wig. However, they would be happy to cooperate in the design of a wig, if that's what the customer really wanted. In the very large sizes they would use ground effect to assist in the take off run but not for cruise. It was not clear what particular features of ground effect they valued for take off. It could have been the paduff or the reduction in induced drag. It seems unlikely that they would have any use for the increase in lift caused by ground effect because more lift is available with conventional high lift devices out of ground effect.

Dr. Volkov gave a little tutorial contrasting ground effect features discernable from a lifting line perspective and those discernable from a 2-D airfoil perspective. He made the point that, for typical aspect ratios, the enhancement in lift due to ground effect as a result of the lifting line phenomena was much greater than that due to the 2-D phenomena. Increasing the aspect ratio reduces the increase in lift due to ground effect and makes is more difficult to develop good longitudinal stability. He also said that they have computer models of the motion of a wingship after impulsive loads. The air under the wing cushions the impacts.

There was a short discussion of the last accident (Orlyonuk). As a result of pilot action, the craft went up (out of ground effect). The pilot did not add enough power for a proper recovery. The craft came back to the water and struck in a slightly nose-down attitude. It's not clear whether or not the craft ever stalled or just flew one cycle of a phugoid. It skipped off the

water again and then hit the second time hard enough to break it. Someone asked whether or not a wave impact could have caused the crash. The answer was no.

The main purpose of the hydroski is to damp overloads during landing.

On 08-13, Mike Francis, Burt Rutan, and I went to Yakolev facility in Moscow. There we met with several people (cards attached). They are becoming privatized. The company will be owned by a combination of the employees and the state in a specified ratio. Their deputy chief of deign and marketing in international affairs spoke. They recently hosted NASA and the USMC who had an interest in the Y-141, a VTOL aircraft. They build the only Russian commercial aircraft that is certified for passenger use on international routes. It's the Y-40&42. They have sold the Y-40 to Italy and FRG. They are working with the airworthiness certification in Canada, UK, and the US. The airworthiness requirements are different. The product line includes aircraft ranging in size from small sport aircraft to those carrying up to 170 passengers.

One of their current design projects is the YAK-UTK trainer. They designed it in response to a 1991 Russian Air Force RFP. They competed with the other Russian deign bureaus. They presented their preliminary designs to the Air Force. They were selected for a second phase with two competitors. A winner may be announced next year. Although, the program is nearly dormant because of the reduction in military spending in Russia. Yak is looking for western partners to keep the design going. They are teamed with Aimarker(?) which is an Italian company with lots of experience in training aircraft. They are building up a prototype with appropriate spares for demonstrations in 1994.

Here is some top level data on the design:
Span=11245mm
Length=12400mm
Max (takeoff) Weight=six metric tons
Fuel Weight= 1760 kg
Maximum Speed=1000 km/hr at sea level
Maximum Sustained Normal Acceleration = five gees at five km altitude and M=.6
Design load factor from -3 to +8 gees
Maximum Mach=.98
Thrust of each of the two engines is 2200 kg (sea level static)
Thrust to Weight Ratio=.7
Take Off Speed= 195 km/hr
Landing Speed= 190 km/hr
Three Channel Electronic Flight Controls for Each Axis
Can fly up to 35 deg angle of attack

They made the point that high alpha training is important. A Russian avionics company makes the FCS. This trainer is beyond the US JPATS. It's an advanced trainer. They do not think supersonic capability is important. They don't think that spins and tail slides are important in

the advanced trainer for more sophisticated machines. The design has special ducts at the top to provide FOD-free air for ground running. The winglets improve cruise L/D by about 10% without hurting the maneuverability (roll rate?) of the airplane.

The airplane can serve as its own simulator to train pilots. There is software to diagnose training flights. They are using our GPS for navigation and a dedicated system of their own for approach and landing. They can simulate dropping bombs and other weapons. There are hard points designed into the wings. They measure angle of attack from the pressure distribution around the nose.

They discussed the development of the YAK 141. Development of the YAK 138 (the 141's predecessor) was started in 1960-61 roughly parallel to the Harrier. The take-off weight is nine metric tons. The lift thrust is provided by two engines of 5700 kg thrust each. Roll control is by tip jets. They were required to use in-country engines for the design. They made 200 YAK 138s. The vertical lift engines had a life of about 450 hours. They operated at gross weights from 8.5 tons to 11.5 tons. The 138 had a mechanical flight control system. Its top speed was 1100km/hr. The possible normal acceleration ranged from -3 to +7 gees.

The YAK 141 was developed from 1980 to 1989. The customer wasn't happy with the 138 and sought a better design. They wanted a truly supersonic design for ground attack and point defense. The maximum speed in 1800 m/sec at altitudes of 5 km and above. The maximum Mach number is 1.8. The top speed at sea level is 1250 km/hr. The maximum weight for vertical take off is 15800 kg, and the maximum weight for short take off is 19500 kg. It can operate to a radius of 690 km carrying a 2-ton payload.

To do a program like this they get a block of money and hold out a management reserve.

The 141 was first deployed only on ships because they had deck surfaces that could stand the heat. They can use concrete ramps for a while, but they eventually fail.

They did consider other arrangements such a combined lift and cruise engines. They agree that combined lift cruise engines would result in a lighter design with less frontal area. However, they were driven by tradition and experience to the dedicated engines. Their lift engines have a trust to weight ratio of 12:1.

We traveled to Nizhney Novgorod on Saturday evening and arrived Sunday morning. CHDB personnel met us with a bus at the train station and took us to the hotel. Business began on Monday morning at the Central Hydrofoil Design Bureau.

Admiral Polanskii emphasized that they had assembled people from all over Russia to demonstrate their comprehensive coverage of the Ekranoplan subject. The CHDB, on this site, has a long history of technical accomplishment.

Dr. Chubikov said that all of the wigs were built here. He congratulated us on the status of our

delegation and said that his team was similarly well qualified and carefully selected. He believed the community needed to develop a new vision of sea transport. He believes that take off weights of 2- 3000 tons were technically feasible. He claimed to have several proposals for cooperation but was not specific. He said that his agency intended to continue developing wingships. He introduced his team.

Mike Francis described our team as neither hyper critical or advocates. Said that our team wanted to give the WIG the best possible chance and that we've come to understand other applications. Our study has two parts -- technology and missions. WE are scheduled to make our report by November. WE intend to begin phase II ASAP. We are looking for areas of cooperation. Francis introduce our team.

Chubikov introduced CHDB work. Alexeyev started the whole thing. Alexeyev is personally responsible for Russia's emphasis on hydrofoils and wingships. They have built 30% of the worlds hydrofoils. (I learned from other sources that Russia has built more hydrofoil boats than any other country.) They have sold hydrofoils to many countries -- 35 to Greece alone. They built 600 of the Raketa (Rocket) hydrofoils over a period of 30 years. The newer Meteor carries 120 passengers, and they have built it also for 30 years. All together they have built 1500 hydrofoil ships. They also have built 6000 (may have this number wrong) smaller hydrofoil boats. They gave one to Nixon. They now have three hydrofoils in development. The gas turbine powered Cyclone will carry 250 passengers at 45 knots. The diesel powered Olympia is to be used on a run from Paris to Stockholm. On its delivery run from the black sea to Estonia it operated in 3.5 meter waves without damage.

They have built two or three air cavity boats. They have both passenger and cargo applications.

The wig development in involved research from multiple research institutes. The Russian Navy got an early report on their progress on wigs, and that's what started their big program. They have started work on passenger craft. They have designs which carry from five to eight people, designs around 150, and designs around 250 people. They are prepared to cooperate on passenger wingships. Large wingships are more efficient. There will be competition with other means of transportation on the world market.

Concerning the development path one can go by gradual stages or by leaps. Alexeyev was right to do the 500 ton CSM early. It defined the most important problems early in the program. Chubikov believes that the optimum take off weight now would be somewhere between 1000 and 3000 tons. All their data and foreign studies indicate an optimum in this range. CHDB has had good experience up to 500 tons.

They overcame major problems. They solved the dynamics problem at all speeds. They have an adequate approach to propulsion in the marine environment. They have make fully welded aircraft like structures.

Their main aspiration is to raise the efficiency.

There are several new problems to be addressed. There should be more research into applications and marketing. They should build two to four machines in the range five to five thousand tons. They should continue to press for a way to certify the craft internationally.

We then made an attempt at a group session of questions and answers. The format was all of our guys firing questions at the current LUN designer who was supported by his staff. The LUN designer answered all the questions.

Gene Covert:
Q: Were is fuel carried in the LUN?
A: IN the wings. A small amount in the tail.
Q: Is your welded aluminum as strong as tempered aluminum?
A: Just used weldable material so far. Close to having a high strength weldable alloy.

Czimmek:
Q: Do you relieve manufacturing stresses?
A: No answer.

Wilson:
Q: What are the main design loads; high speed impact or sea sitting?
A: High speed landing loads.

Rutan:
Q: What is the highest speed for landing?
A: Can survive landing and take off in 3.5 meter waves. Can touch the water at 450 km/hr.

Covert:
Q: What is the maximum landing weight?
A: 80% of the take off weight.

Rutan:
Q: What is the maximum speed for full flaps?
A: Approximately 350 km/hr

Reeves:
Q: What is the limiting Mach number?
A: The flutter speed in 120 km/hr above 500 km/hr.
Q: How many engines are in operation in cruise?
A: All are on. In an emergency they can cruise on any four engines.

Savitsky:
Q: Describe the individual impacts and take off and landing speeds.
A: The first touching of the water during landing does not drive the design. Subsequent impacts do. The hydroski helps. The main structure touches at 270 km/hr.

Q: How many gees do you experience on the hydroski?
A: About two gees.
Q: What does the hydroski weigh?
A: No answer.

Covert:
Q: What is the wing limit load?
A: It is designed for seaworthiness.
Q: Is it designed for strength or fatigue?
A: It is designed for both strength and fatigue.

Gera:
Q: Does the craft operate at near constant angle of attack?
A: Yes. Height depends on speed and thrust.
Q: What are the functions of the auto controls?
A: None or not recorded.

Czimmek:
Q: What are your safety factors?
A: Use aviation type safety factors that are different for each component. They range from 1.2 to 2.

Gera:
Q: Is it naturally stable?
A: Yes. Auto control system provides additional damping of some modes.

Wilson:
Q: Is it stable both IGE and OGE?
A: Yes.

Rutan:
Q: Where is the CG?
A: Won't answer. CG range is small but adequate. Major quantity of fuel is located on the CG.

Covert:
Q: Is it a wet wing?
A: Yes.

Covert:
Q: Are there limber holes?
A: Yes.
Q: Any stress corrosion problems in fuel tanks?
A: No.

Fluk:
Q: What payload and range did you design for?
A: Classified.

Gera:
Q: What was the cause of the last crash?
A: Pilot error.

Savitsky:
Q: To what extent is salt a problem?
A: Worked with engine specialists to get solutions.
Q: How many hours between washes?
A: Wash engines on every flight on some installations. Only one was per year on others.

Fluk:
Q: How many take offs and landings before an engine change?
A: Use just service life, not cycles. They are military engines. Use them about 700 to 1000 hours.

Reeves:
Q: Why didn't you use turboprops?
A: We do use them on some designs.

Fluke:
Q: Have you considered a long life commercial aircraft engine?
A: Now working on this problem.

Covert:
Q: What is rate of normal acceleration increase with elevator angle and cruise speed?
A: Not relevant for ground effect flight.

Rutan:
Q: What is the elevator activity in turbulence and waves?
A: Less than 5 deg.
Q: What elevator displacement is required for takeoff?
A: 20 deg each way at different times during take off.
Q: What is the maximum flap deflection?
A: 20 deg.
Q: Will the flaps deferentially as ailerons?
A: Yes. And there is some aileron control left at the maximum flap deflection.

Francis:
Q: Has the LUN been flight tested at altitude?
A: Not yet. We're working on it.

Camp:
Q: What is the longest flight?
A: 2000 km in about 4 hours.

Rutan:
Q: Earlier craft had a vertical fin apparently to generate lateral forces for turning. Why did you delete it?
A: It was inefficient.

Fluk:
Q: What is the ferry range?
A: Don't know.

Rutan:
Q: What is the turning radius?
A: No answer.

On tuesday we took a hydrofoil boat to the test site near Chkalovsk. The trip took about two hours. Individual conversations during the trip yielded a fey nuggets of information.

Dan Savitsky learned that they use a gee load of 3.5 gees plus a safety factor of 1.8 to yield. (Len Malthan should use a similar factor in his parametrics.) Hydroski weight is typically 4-6% of gross weight.

Eric Lister had a good interaction with their propulsion specialist and got most of the information he needs.

That evening (Tuesday) we had a WTET caucus at the hotel. The general perception was that we weren't getting some of the information we needed to understand the Russian technology and get it into our report. We decided that the main problem was that the Russians that had the information we sought were not getting much of an opportunity to speak. Therefore, we decided to force the next session to be in smaller groups organized into topical areas where we needed the most help. The topical areas turned out to be: (1)missions and applications; (2) flight test; (3) structures, seaworthiness, and materials; and (4) design. Mike conversed our request forcefully to RAS and they said that they would see what they could do.

The next day's meeting (Wednesday) started with a presentations by Sakalov who is the designer of the Orlonuk. He described the Russian history in ekranoplan development as three phase program. The initial goal was to beat the performance of hydrofoils. They saw an absolute limit on the speed of hydrofoils at about 60 knots due to cavitation. Since this was only marginally above the speeds they had already achieved, a new technical approach was required.

IN the 60's there were theoretical and technical studies. There were tests and some experiments ranging from 1.5 to 2 tons. They tried to learn the appropriate scaling rules and how to achieve

stability near the surface.

He presented a chart showing volume Froude number on the above axis and power required per unit weight on the vertical axis. Moving from the lower left to the upper right are three areas. First is air cushion craft. In the middle are Volga II type craft. At the upper right corner is the Strichz type or Ekranoplan.

The Ekranoplan has evolved to a configuration that uses paduff to take off and a hydroski for landing. The amount of blowing and the relative size of the hydroski is specialized for each craft.

Sakalov gave a brief history of the developments leading up the CSM. He has been continuously in the business for thirty years -- since getting out of University.

1961	CM1	2.3 ton
1962	CM2	3.2 ton
1963	CM277	6.3 ton
1962	CM3	3.4 ton
1964	CM4	4.8 ton
1964	CM5	7.37 ton
1965	CM8	8.1 ton
1967	VT1	0.7 ton
1966	CSM	500 ton

Sakalov then gave a description of their wingship design process separated into structures, layout, controls and instruments and his vision for future designs.

On structures they initially used TSAGI data and recommendations. From that they developed the strength requirements. They tested elastic models (both Froude and Reynolds) to get requirements. They correlated data with the CSM. Considered both dynamic loads and fatigue.

Their sequence in design is to: (1) chose the layout; (2) find the optimum wing loading (apparently based on a speed requirement and a knowledge of the lift coefficient for good stability IGE) and; (3) find the stability foci as a function of height, angle of attack, aspect ratio, and end plate depth.

They have had some problems with automatic controls. All wingships have static and dynamic stability. The Volga II stays in strong ground effect and is naturally stable. The Strichz is more maneuverable and is stable both IGE and OGE. Only the LUN and Orlyonuk have damping and stabilization.

They have had to make some accommodations to operate in the sea environment that detracted from performance. They use an aluminum and magnesium alloy which has about 2/3 the strength of high strength aluminum alloys. In future designs they would propose to use new alloys of their own or use US alloys. Examples are Lithium and Scandium alloys of

Aluminum. They used aviation engines modified for the marine environment. They would expect some improvement in engine performance with an on-purpose design. They believe that to achieve adequate safety in flight control that they need a robust height measurement.

So far, they have been designing only for military requirements. They are now trying to meet requirements for civil operation. They want to improve the max L/D. It's now 25 and they seek 30. The hydroski now has an L/D of 5 to 7 and they would like to go higher. They recognize the need to get the empty weight down.

Sokalov described three size ranges of ekranoplans. All require a static thrust to weight ratio of about .25. Up to 500 tons he believes the airplane configuration is best. Around 1000 tons, he believes the flying wing configuration is best. The originally had design concepts from 1000 tons to 5000 tons that would be nuclear powered. Now this last design concept has evolved to the chemically powered craft in the 300 ton range.

They now believe that the practical limit for the number of engines is 10. Since new engines are rated at about 40 tons they see a 2000 ton limit based on engine technology alone. However, Sakalov felt that was too large a jump from the present 350 ton size and recommended a 800 ton design as the next logical step. He thought all applications studies from now on must be dual purpose.

They said they could answer practically all our questions and that they would do that in stages.

Sakalov seemed to like the idea of designing craft to meet a requirement as opposed to just making something and seeing what it does.

The 800 ton machine would be a flying wing or a multiple wing configuration. The high L/D they sought (I took this to be 25 or 30) would be for smooth water only. In sea state 4 or 5 (3.5 meter waves) this would degrade to 20 or 25.

Dr. Dimitov reviewed the efforts they had made on the development of automatic controls. In 1964 they built the two-person ANT 25 which cruised at 130 to 140 km/hr. They made 42 flights in it. He personally flew it with Alexeyev.

In 1967 they flew the CSM which had instruments to guide the pilot but (to my understanding) no automatic control system. In 1974 they flew the Orlyonuk which has a flight control system. In 1986 they flew the LUN which has a newer version flight control system. There have been a total of 1500 hours of trouble free operation of the Orlyonuk and LUN flight control systems.

The first considered the autopilot as just an add-on. Its specific purpose was to reduce the pressure on the pilot during night operations. They did not manage to build a large ekranoplan that had satisfactory natural stability. They decided that they must have automatic flight controls.

They divide the problem into several general areas. The system must damp the system about all three rotational axes. It must establish the proper trim condition for each speed of flight. It must assure speed stability.

IN the cockpit, the system must provide appropriate angle limit warnings to the pilot. It must provide means for the pilot to trim the controls. It must provide for control of the engines and provide appropriate switchology and fault detection.

They achieve reliability by hardware redundancy, equipment redundancy, signal mixing and selection, and appropriate rate and displacement limits. They use equipment from the aviation design bureaus.

Special control system problems peculiar to ekranoplans are: (1) wave height measurement; (2) navigation; (4) demanding angular rate limits; and (5) control surface overloads. They must stabilize pitch angle within a very narrow angular range. Typical aircraft type control requirements are not appropriate.

Course turning is unique. It requires the operation of all controls and combines sideslip and bank. The rule is to maintain the clearance at the inside wingtip. Therefore the pilot must know what this clearance is. First they did it with a rear view mirror. Later they used direct measurements of the tip clearance.

The CHDB intends to use this institute for all future designs. They have had no accidents attributed to the FCS. The systems were delivered on time. There have been no flight test holds attributed to FCS. The systems provided effective damping and improved stability. The systems made it possible to stabilize the craft at otherwise unstable parts of the envelop to achieve better L/D.

Among new things they would do on the next FCS are: (1) control large scale vertical maneuvers; (2) automate the take off and landing runs; and (3) optimally allocate functions between manual and automatic.

He made the point that flight control work should start early in the design process. He also mentioned that they used a simulator in their FCS development work -- although no on the WTET saw it.

That ended the formal presentations for a while. We then broke up into the small groups we defined the previous evening. I joined the design group which included americans John Reeves and Hal Fluk and Russians Sokalov, Sidirov, and Ruston Bagishev.

John Reeves began by noting that different design groups in Russia seem to favor different configurations. Irkutsk is associated with the flying wing. Tagnarog (specifically Bartini) was associated with a combined planform with high aspect ratio and low aspect ratio parts.

In response, Sakalov noted that they settled on the low aspect ratio aircraft type configuration at least partly to get good behavior over waves. For example, they made extensive studies of the tandem wing configurations and found that they were too closely coupled to the surface in pitch. This coupling caused a number of accidents and crashes. They concluded that the tandem configurations were only useful in a very narrow altitude range.

However, Sakolov believes that at very large sizes the airplane configuration becomes less desirable. At 800 tons he believes the craft should be a spanloader or flying wing. He definitely wants a tailess version over 600 tons. The reduced tail area will help the L/D a lot. He believes that careful shaping of the wing will result in adequate stability. He agrees that the hydrodynamic features such as steps and spray strips are major drag producers but didn't make any specific suggestions on how to reduce this drag.

Roger then discussed the typical western systems engineering approach of first developing requirements and then designing to them and asked Sakolov what items should be included in a top level set of requirements. The minimum list came out to be: (1) payload description; (2) range; (3) height of waves; (4) loading and unloading infrastructure; (5) take off and landing distances; (6) gust conditions; and (7) basing. We then asked him to fill in this table for the existing craft and for what he thought he could design in the future.

REQUIREMENT	EXISTING TECHNOLOGY		NEW TECHNOLOGY	
Payload	80 ton	80 ton	150 ton	500 ton
Range (km)	2000	2000	5000	12000
Wave Height (m)	3	3	3.5	4.5-5
Loading	Dock	Dock	Dock	Dock
Turn Rad (km)	4	3.5	5	10
TO Dist/Time	1.5m/3.5km	90s/3.5km	2m/5km	5km
Basing	Optional	Opt.	Sea	Sea
Cruise (km/hr)	400	400	450-500	600
TOGW (mtrc tns)	350	250-280	800	2000

Human factors are very important above 450 km/hr. Similar on all vehicles. Must get the pilot high!

Sakalov said they had several problems they had to work on to make better craft. He thought the L/D and the speeds they could achieve would be economically attractive. They need better engines with lower fuel consumption. The empty weight fractions must get better. They must keep the cost lower than an aircraft that can perform the same mission.

They can safely clip the tops of the waves in sea states three to four. (He could have meant wave heights in meters.) They use full elevator control for takeoff and landing. They limit available elevator travel in cruise. Pilots must be trained for ekranoplan operation. He believes that a flying wing design could be all near the surface -- that is, it may not require an OGE part to stabilize it.

Concerning de-icing, he said that the inlet lips were hot, the leading edge of the wing is taken care of by the paduff, and the rest of the craft requires a dedicated deicing system. In big designs it may be most practical to use a Diesel engine for low speed maneuvering. Such an engine could use the same fuel type as the turbine engines.

Existing wingship designs did not incorporate all advantages. The first designs satisfied mainly tactical requirements and did not emphasized either efficiency or cost. There were always competition with the aircraft community approach to designing to the same requirements. There were positive aspects of this competition. They could find quite a bit of aircraft type equipment that they could qualify for wingship applications. Additionally, since the wingship environments were, in some ways, less demanding than aircraft requirements, they could find some non-aviation equipment that they could qualify.

We took the train back to Moscow on Wednesday evening.

On Thursday a small group of us visited the TSAGI location in Moscow. Our objectives were the simulator and the hydrodynamic testing facilities. I joined the hydrodynamic group. Mike joined the simulator group.

TSAGI/Moscow has 850 people in four major departments. They are: (1) low speed aerodynamics; (2) aviation acoustics; (3) hydrodynamics; and (4) scientific information services. The scientific information services department services the whole aviation industry -- not just TSAGI.

They do research on ekraloplans as a class as opposed to the facility at NN which models specific craft. They strive for static and dynamic stability and make recommendations to the designers which they can accept or reject. They only make recommendations for flight procedures IGE. They are the clearance authority for OGE flight. They clear every flight of the Orlyonuk and LUN. They believe that a 1200 ton design could achieve the same efficiency as a good subsonic aircraft but not much more. It would have to be loaded and fueled at docks. It would be for commercial operations. Here are some estimated technical characteristics:

Flying Height= 5 meters
Payload = 400 tons
Range = 6000 km
L/D = 26-30
W/S = 600 kg/m^2

Before 1990 there was shipbuilder and aviation activity in the program. When they started contemplating OGE ferry flights weather avoidance, the Navy realized that is was essentially an aircraft an had to be handled that way.

Our tour included two wind tunnels and one towing tank.

They also do most of the model testing for seaplanes. In fact, they have been doing seaplanes for longer than they have been doing wigs. Wingships have some peculiarities. For example, they can almost completely model seaplanes by adding aerodynamic, hydrodynamic, and propulsion forces. They have not been able to made a similar model for wigs because of the strong interactions of these effects. The paduff complicates the situation a lot. Also, the wigs tend to have many complicated and interacting hydrodynamic features.

A seaplane hull has a maximum L/D (at its worst speed) of about four to five. The corresponding value for a wig with paduff is about six to seven. The flaps blow back under hydrodynamic loads in all their large designs.

They have found that, if the beam of the model hull is greater than 300mm, Reynolds effects are negligible for Froude scaled models.

Information on Issues Related to Structures

and Other Subjects Obtained During Visit in Russia

FROM: Dieter W. Czimmek, NNS

TO: Wingship Technical Evaluation Team (WTET)

The following information, which may be of interest to other members of the WTET, was gathered from Russian presentations, group discussions, person-to-person conversations, and observations during the tour of the "LUN" wingship. Also, I would appreciate any corrections from the WTET in the event that I have misunderstood some of the information.

1. **Information Related to Structures**:

The basic structural design philosophy for the Russian wingships apparently evolved from the technology of hydrofoil boat design rather than from the aircraft design technology.

The strength calculations of the Russian wingships are based on the full take-off weight, and no reduction is made for burned fuel after take-off (Fomin, CHDB). On questions concerning the maximum design conditions, Fomin stated to me that for the wings and fuselage the landing mode is-giving the highest governing loads. For the wings the extreme loading case is when the vehicle is slightly rolling while landing and the endplates impacting the water surface. Fomin also said that they measured maximum impact pressures of 15 kg/cm^2 (213 psi) during landing on fuselage plate panels of the LUN.

On my question to Dr. Sokoliansky (TSAGI) on take-off and landing speeds, he quoted 370 km/hr (200 kn) for the ORLAN and LUN. This agrees fairly good with the 360 km/hr (194.4 kn) quoted during the open questioning period at the CHDB on August 17, 1993, for the LUN maximum landing speed with the wing flaps down. At the same time, a maximum possible landing speed of 470 km/hr (253.8 kn) in 3.0 meter waves with flaps up was quoted for the LUN. The waterborne speed of 270 km/hr (145.8 kn) was used for designing the vehicle structure according to CHDB, using a factor of safety of 1.8 for impact type loads.

A factor of safety between 1.2-2.0 is used for wings and fuselage structures depending on the loading condition and structural location. This agrees fairly good with the Compendium. For in-flight loads they apparently use a factor of safety of 1.5 according to the Compendium. CHDB also claims that they design for strength and fatigue. But

on questions on this subject, they would not give any number of cycles related to S-N curves of their basic materials for particular structural components. Flutter was a design consideration according to CHDB.

During the open discussion on August 17, 1993, it was confirmed that the take-off and landing modes provide the governing design loads for the wings and fuselage. Seasitting for higher sea states was not established as a design condition by CHDB.

Regarding my question on stress corrosion precautions, CHDB replied that they take stress corrosion into account during their design. Although, they do not worry about carrying fuel on bare aluminum, a question G. Covert brought up. Fuel is carried in the wings only and no correction of the C.G. is being made as fuel is burned. Apparently, the fuel C.G. is close to the vehicle C.G. that it does not make much difference.

The wings are provided with a through-structure in way of the fuselage which was confirmed by my observations of a bolted connection along the circumference of the wing-fuselage interface. This was also confirmed again by Narizin during the group session of August 18, 1993.

The exterior wing and fuselage structure is welded throughout, except for fairing plates and the cockpit structure which are screwed and riveted. This is either due to the use of high-strength aluminum or the skin plating became too thin for welding. The same was noticed for all interior transverse bulkheads which were all riveted and screwed. One reason for the interior structures being designed to aircraft practice was most likely to reduce structural weight, since it is more protected from the corrosive outside environment and high-strength aluminum could be used. The other reason, again, could be that the plating became too thin for welding.

Weld reinforcements on wing and fuselage welded seams and butts were left intact and were only ground smooth. All welds seemed of good quality and are being inspected by X-ray and ultrasonic methods according to Narizin.

On a question to a fabrication manager if wing and fuselage panels have to be straightened after welding, the answer was positive. But how it was done was considered proprietary information by him. In several locations, I noticed doubler or insert plates protruding over the regular fuselage skin surface. Those could be in way of highly stressed locations (there were no openings). The inside of the cockpit was lined with fiberglass panels between the stringer and ring frame flanges to reduce outside noise from the engines.

With respect to anti-corrosion measures on LUN, the following was observed. The outside fuselage showed several areas of paint which seems to be anti-corrosion zinc-

chromate paint. All outside surfaces will be coated according to CHDB. In addition, several bolted-on sacrificial zinc anodes were installed at the aft end of the underwater fuselage (my assumption).

During the group session of August 18, I addressed the question of structural weight fractions to Narizin of CHDB. He provided the following information. The structural weight fraction for the LUN is 0.34 on a normal GTOW of 350 tons, yielding a structural weight of 119 tons. The structural weight fraction for the ORLAN is also 0.34 on a normal GTOW of 125 tons, yielding a structural weight of 42.5 tons. Narizin also quoted an empty to gross weight ratio of 0.50 for the LUN and the ORLAN. The structural weight fraction for the Caspian Sea Monster is higher than 0.34, but this is due to a lot of special equipment which was carried on the C.S.M. The structural weight fractions for the STRIZH and VOLGA II are between 0.28 and 0.32 according to Narizin. If all of the above figures are correct, the structural weight fraction of an ocean-going wingship could be around 0.35 which would make the wingship concept more feasible.

2. Information Related to Other Subjects:

During the Russian presentations on August 18 by CHDB, I addressed Mr. Sokolov on the maximum size of wingships they would feel confident with to design and build right now, based on their present technology. The answer was 800 tons TOGW. Sokolov added that other wingship concepts besides the one used now would be investigated with increasing vehicle sizes. They have performed tests for a 1,000 ton TOGW second generation vehicle (the TSAGI towing tank suggested that a 1,200 ton vehicle would be feasible). Sokolov added that third generation vehicles could possibly go up to 5,000 tons TOGW for which nuclear power could be considered as well.

On my request for clarification of the purpose of the hydroski on wingships, Mr. Sokolov explained that the hydroski is only required for landing in waves, not in calm water and not for take-off as it was suggested by others.

During the visit to the TSAGI model towing tank facility on August 19, the following information was obtained. According to Professor Logvinovich, the TSAGI towing tank has done testing for the ORLAN and LUN in the take-off and landing modes in the tank and on the MOSCWA river using a speed boat as the towing carriage. To measure impact pressures, they also used a ramp from which the model was launched. Also, Logvinovich claimed that they have tested the model in the cruising mode hitting wave crests. I was not too impressed with their facilities and would have reservations about the quality of their results, especially related to tests in waves.

During the discussions with Dr. Sokoliansky and Mr. Makienko at the towing tank, the question of avoiding extremely large waves (rogue waves) during cruise in ground-effect was raised. Apparently, they have studied the problem of flying over obstacles with cruise power only and Mr. Makienko provided me with some information on this subject (see attached figure).

NOTES FROM RUSSIA VISIT
BOB WILSON

• The EKRONOPLAN was designed for open ocean operation and research was conducted for it to have that capability but the craft had been built for local regions. No long range operations are or were planned - it was purely defensive. Regarding transoceanic operations, they have only been thinking about it. They are not currently interested in large EKRONOPLANs for transport.

• Several countries have expressed interest in purchasing EKRONOPLANs but the WTET is the first delegation dealing with research.

• VAdm Polyanskii noted that EKRONOPLANs and seaplanes are both good - for appropriate applications. They are interested in more research for EKRONOPLANs and less for seaplanes.

• The EKRONOPLAN is built by the Navy and used by the Air Force.

• Historical discussion by Mr. Fomin of CHDB. The Russians started studying in-ground-effect flight in the 1940s and combined with hydrofoil studies in the 1950s. They were interested in an aircraft with a water take-off and stabilized motions in take-off. They used a lot of trial and error methods and built special facilities in Nizhny Novgorod with their experimental base located there. They went from models to 5-7 ton prototypes. With Navy support, they proceeded to develop KM. This 450 ton prototype was built between 1961-66 and flew in 1966, achieving speeds of 500 km/hr. It operated with a payload of 40 tons.

• Future, larger Wingships should be configured closer to a flying wing with no fuselage for better performance. It would use air ejectors and ventilators.

• With underwing blowing (PAR), structural loads are reduced.

• Russian EKRONOPLANs have aerodynamic and economic characteristics similar to large airplanes.

• Future Wingships should consider a multi-component wing where it has a higher aspect ratio and the section closer to the root gets most of the blowing.

• For underwing pressures greater than 500 kg/m^2, a highly directed jet stream is needed to provide the air and a lot of spray will occur and the velocities may approach M=1. They don't know whether a pressure of 1500 kg/m^2 is possible.

• Accidents have resulted from high pitch angles and wing stall during take-off. When they stalled, they fell.

• Mr. Volkov noted that the Wingship is a bad aircraft and should be operated as a boat.

• Wind tunnel tests are conducted in three ways: near a fixed, immobile screen; with a model and its image; with a mobile screen. The best results were with the mobile screen.

• The hydro people from Krylov would like to see the Wingship keep to a speed of nominally 350 km/hr.

• ORLAN has a flying weight of 140 ton and LUN flies at 400 ton.

• When KM was developed, the average age of CHDB's engineers was 25-26.

• Alexeyev was the key player in the development of KM and kept the funds coming in.

• Structural materials and avionics of early EKRONOPLANs were more ship-like than the technical level applied to aircraft. The aluminum used was 1.5 times less capable than that now in use by the Russian shipbuilding community.

• The design loads come from maximum weights and conditions during take-off.

• The weight of KM was increased from 430 ton to 500 ton.

• The Russians use existing aircraft engines which have been maximized. They want engines specifically designed for Wingship operating conditions with lower sfc's in these low altitude conditions.

• Their experience has been that for small EKRONOPLANs, they have Thrust/Weight ratios of 0.25-0.30 at take-off. For large EKRONOPLANs, this ratio is 0.20. They indicated having Thrust/Weight = 0.1 at cruise but this is higher than reported Lift/Drag ratios of 15-17.

• They reported design studies for 1000 ton Wingships with L/D of 30+ and a range of 10,000 km. This L/D is achieved at a h/c of 0.1.

• They would consider using titanium for Wingships up to 1500 ton and are interested in composite technology combined with titanium.

• Mr. Chubikov noted that they want to have the Wingship accepted internationally and certified as a flying ship, not an airplane.

• The Research Shipbuilding Institute (RSI) of the Ministry of Defence developed requirements for Attack and Cargo transport missions.

• Control by the RSI over R&D was established.

• The unusual construction of the EKRONOPLAN presented unusual problems for the use of weapons on a platform traveling at speeds up to 500 km/hr. They adapted and used weapon and equipment systems already in their inventory.

• ORLAN is amphibious and is to take people, ammunition and equipment on to the beach.

• LUN is a waterborne platform with an established life cycle based on ship experience.

• Installing the missiles on LUN took a lot of effort and was a poor aerodynamic solution, reducing L/D. Launching the missiles at 500 km/hr had little impact on the platform; LUN's altitude reduced slightly and immediately regained it. Several missiles were launched with no rolling motion.

• Moving the Wingship from one theater of operations to another as well as the need for targeting will require the ability to fly at altitude for some length of time.

• The Russians look at the EKRONOPLAN as a low observable platform, operating in wave clutter. Spray effects create a heat shield for reducing engine IR signatures.

• They accumulated vast experience with the EKRONOPLAN and ASW, using acoustic and non-acoustic equipment.

• They currently see it as the best submarine rescue craft, carrying up to 150 wounded or 500 people total. Their studies show that the EKRONOPLAN can carry more cargo and has better characteristics than a seaplane.

• They have conducted tests for taking on people in rubber boats in SS-4.

• They equated the 30 year development of the EKRONOPLAN to the cast of their stealth program development.

• ORLAN was a pilot program including the land basing. They built 5 and no more due to lack of funds.

• Hyrodynamic and aerodynamic testing is done at Krylor Shipbuilding Research Institute, TsAGI (Central Aerodynamic Institute) and by the facilities of CHDB in Nizhny Novgorod. The Designers/Constructors at CHDB pick what they want to use.

• They noted their work on the 600 ton hovercraft and the 1000 ton SES. They wanted to beat everything that the U.S. did.

• LUN is 80% complete but it would take a year to have it ready for operations.

• They stated that a 1000 ton wingship should be the next step.

• TsAGI said that it makes recommendations regarding the EKRONOPLAN's aerodynamic configuration and gives clearances for first flights.

• The A-40 Albatross has a take-off weight of 80 tons, flies at 750 km/hr and takes off at 200 km/hr.

• Spray problems are similar between seaplanes and EKRONOPLANS.

• Hydrodynamic facilities include towing channels with speeds up to 60 m/sec, high speed motor boats which tow the models and have pilots that fly them (and train on them) and radio control models.

• TsAGI believes that the current EKRONOPLAN is not a safe design to fly out of ground effect.

• Profile drag reductions can come from a flying wing.

• In high seas, they like to fly nominally 3.5 m above the crest of the average waves.

• TsAGI believes that ORLAN is unstable out of ground effect. CHDB does not concur.

• A 1200 ton design would have 80 tons of thrust for IGE flight and 350 tons for PAR.

• TsAGI believes that it will be very difficult to get L/D = 18+ flying over waves.

• Design wave height is determined by limiting the local hydrodynamic impact load to 4 g's.

• Recommendations from Dr. Rozhdestvenky's theoretical analysis: design for ground effect if you want high L/D; have low to medium aspect ratio for maneuvering and docking; design for large waves in the ocean at lower L/D's; have automatic controls.

• The strength of the cushion under the wing reduces landing impact loads.

• ORLAN fell at a 10 deg angle in their most recent accident.

• The hydroski was usedto reduce landing loads and increase drag - to reduce loads in high seas.

• Experience with ORLAN and A-40 seaplane show that maintenance is much easier if done on land vs LUN in the water or on a floating dock.

• Beriev Design Bureau has a Wingship concept, aspect ratio 6, 300-350 ton, take-off sequence to IGE is 40-50 sec, then climbs to altitude and has a max L/D of 20-22. They feel that is (as a water-based platform) would be competitive with a Boeing 767. Loading and unloading is an issue.

• Beriev notes the need for automatic stabilization for low speed, low flying heights. They fly their magnetic ASW gear at 50 m and personnel are fatigued after 3-4 hours.

• A real world concern regarding seaplane operations is floating debris. They remove floating objects in test areas after storms, prior to first flights.

• Beriev DB noted that civil aviation requires absolute safety. They stated that the EKRONOPLAN has flap safety problems due to wave strikes which can affect flight safety.

• The CHDB has looked at a 3000 ton Wingship. They believe that it is feasible, possible and practical from both a technical and manufacturing viewpoint. But it will call for new approaches.

• Problems were discovered on KM that forced them to go back to smaller craft.

• Chubikov's plan is to: Do Market Research to find where the demand/need is; Build 2-4 platforms getting to 5000 tons; Certify the Wingship at the international level.

• Design loads are due to acceleration in take-off and impacts. Sea sitting is not a design driver.

• The landing load is the design load for the hydroski.

• The LUN can take off and land in 2.5 m waves.

• It is acceptable to touch (Kiss) the waves at 450-550 km/hr.

• The landing weight is nominally 80% of its take-off weight.

• The structure is designed for both strength and fatigue.

• A factor of safety between 1.2 and 2.0 is used depending on the component.

• CHDB states that the EKRONOPLAN is stable IGE and OGE.

• The range of LCG travel is small but acceptable.

• Engines are washed every 1-2 years. Take-off and landing generates the most spray ingestion.

• Flaps are down 20 degrees during take-off.

• Engines are kept running or shut down during cruise, depending on which is most fuel-drag efficient.

• They have only flown OGE for a few minutes and it was a ramp up and down.

• An auto-pilot is used continuously with little or no crew fatigue.

• Blowing under the wing while taxiing reduces drag, reduces loads, and improves seaworthiness.

• Sokolov noted that the hydroski is used during take-off - at lower angles of attack than when landing.

• Model testing includes: wing tunnel tests with mirror image models; tow basin tests with and without PAR; towing in open water; towing over land in special rigs; towing on a rotating arm; use of towing experiments over solid surfaces and then over water (amphibious tests); radio control models.

• Sokolov stated that they have adequate static and dynamic stability.

• The flying height above the surface is measured by two methods.

• All requirements to date have been from the military but they hope for commercial clients and standards soon.

• Sokolov noted that they "can" achieve L/D of 25 now flying very close to the surface and hope to achieve 30 in the future.

• The current L/D or W/T in the PAR mode is 5-7 which they hope to raise to 7-9.

• CHDB has designed an 800-1000 ton Wingship which they have tested on a self-propelled model. They have data on a flying wing now under development.

• For a 1000-5000 ton Wingship, they planned on using nuclear energy but now would use chemical fuel. Their 3000 ton design uses T/W of 0.25 and uses 10 engines with 50 tons of thrust per engine.

• CHDB feels comfortable building an 800 ton design based on existing data but it would look different than the LUN. It s purpose and where used is very important to the design (as it should be).

• High lift to drag ratios are in calm water. Flying above waves at 3.5m, the L/D reduces by 4-5 points.

• For higher L/D, need higher lift coefficients and lower induced drag achieved by higher aspect ratio.

• Flying height is measured relative to the trailing edge of the flap, not the wing end plate.

• CHDB designed and built an automatic control system which solved control problems. It keeps the EKRONOPLAN within limits and remotely controls the engines during take-off and landing.

• There is equipment and functional redundancy in the control system.

• The EKRONOPLAN is very INOBEDIENT to elevation, rudder and ailerons while flying close to the ground. It is normal in OGE.

- During turns at cruise speeds, all channels of the control system are operating to ensure that the clearance height doesn't decrease.

- No accidents were due to the flight control system.

- All systems are currently analog.

- CHDB has a training simulator in Nizhny Novgorod but they do not have waves in the simulator. Vertical motions are calculated but not replicated in the simulator.

- While flying in an EKRONOPLAN, there is no motion other than during take-off and landing.

- During take-off, you clear the water at about half take-off speed or about 190 km/hr.

- The hydroski is lowered about 0.4 m during take-off in waves. It is max down (1.5 m) when landing in waves.

- They like to keep a flying height of 0.1 h/c above the top of the waves.

- If the pilot must fly high, he will - at the height that he feels most comfortable with.

- The equations in the compendium for flying height are about correct.

- The flight path angle at landing is about 0.5 deg.

- During landing, the hydroski touches at about 270 km/hr.

- The impact load requirement for LUN is about 5 g's. This is nominally an expected load of 3 g's with a factor safety of 1.8. Flight test experience to date is 2 g's in a state 5 sea during landing

- Flight test experience of end plates or the fuselage hitting a wave during IGE flight has produced only 0.2 g.

- They have experienced local impact pressures of 20 atm (or 300 psi).

- Wing thickness in areas nonadjacent to the fuel tank is 5-6 mm (0.22 in).

• The hydroski is 2/3 width of the fuselage.

• The structural weight fraction of LUN and ORLAN is 34% of their normal take-off weights of 350 ton and 125 ton, respectively.

• LUN and ORLAN have a 50% empty weight fraction.

• For future improvements, they need stronger, weldable materials. Titanium can be used up to a 1500 ton Wingship.

• A different fuselage lay out will also reduce structural weight. Improvements of 2-3% can be hoped for.

• CHDB has considered composites but only for small EKRONOPLANs.

• Since EKRONOPLANs have crashed and broken up, CHDB is worried about reducing structural weight significantly.

• On a big Wingship, they look at composites for components - since they have little experience and no money to do the development.

• The design of a 1000 ton Wingship would take about 1.5 years with delivery in 4-5 years from go. A big problem is the Russian infrastructure, and delivery of parts, etc.

• The structural experts said that they don't need data from LUN - just send money.

• They are considering a flying wing or a compound wing for the next generation Wingship.

• What future efforts: navigation equipment, digital flight control system, engines designed for Wingship, new materials such as composites, tests on U.S. hydrodynamic towing carriages, possible improved panel pressure measurements on LUN.

• TsAGIs results are recommendations to the CHDB.

• TsAGI provides flight clearance for intermediate altitudes. They have previously issued clearances for IGE and OGE.

• Krylov has the say when the EKRONOPLAN is in contact with the water.

• TsAGIs 1200 ton design would be totally different than LUN. It would fly at 5 m, have a wing loading of 600 kg/sgm (132 lb/sq ft), range of 6000 km, 580 km/hr cruise speed and an L/D of 26-30 at 5 m.

• Prior to 1990, the Navy was the customer for the EKRONOPLAN and Krylov was the chief institution for shipbuilding. Now (according to TsAGI) the Krylov does ships and TsAGI does aircraft based on the water.

• In TsAGIs opinion, all technologies are of equal importance relative to further development. They did highlight the need for marinized engines capable of producing 43-47 tons of thrust.

• In TsAGIs opinion, take-off and landing is the toughest part of the EKRONOPLANs operational envelope.

• The preferred take-off is in head winds and a head sea.

• Spray and spray/jet generated flow problems do not scale model to prototype and often, must be fixed on the full scale hardware.

• We heard no consistent point of view regarding steps on the hull and end plates. They use several steps which are smaller than those on seaplanes.

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Trip Report

WINGSHIP TECHNICAL EVALUATION TEAM (WTET)
Visit to
Moscow and Nizhny Novgorod, Russia
August 8 - August 21, 1993

FROM: Dr. Daniel Savitsky
Stevens Institute of Technology

1. Background

The objective of this visit was to visit with Russian experts to review the status of technology related to Ekranoplanes (Wingships) and to discuss possible application of the concept. Fourteen of the 16 members of the WTET made the trip - Messrs Hooker and Maltham did not attend. Lt. Col. Mike Francis was leader of the team and Dr. Roger Gallington was his technical advisor. Messrs Jorge Lange and Anatoliy Shistukin of Russian American Science, Inc. provided the necessary liaison with the Russians.

Meetings were held with representatives of the Russian Navy; Krylov Shipbuilding Research Institute; St. Petersburg State University of Ocean Technology; Central Aero-Hydrodynamics Institute (TsAGI); Central Hydrofoil Design Bureau (CHDB); Beriev Aviation Scientific and Engineering Complex; and Central Scientific Research Institute (St. Petersberg). The meetings took place at the Ministry of Defense (Moscow); conference rooms in the President Hotel (Moscow); CHDB (Nizhny-Novgorod); TsAGI (Zhukovsky); Kremlin (Nizhny); and TsAGI (Moscow). The team arrived at the President Hotel on Sunday, August 8, 1993. The following is a summary of the presentations at the various meetings:

2. <u>August 9(AM) Ministry of Defense, Moscow</u>

Vice Admiral V.A. Polyanskiy, Director of Naval Shipbuilding, welcomed the WTET. He stated that there was a new atmosphere in the Russian Navy. Rather than being secretive and distrustful of the United States, the Russians are now looking to cooperate with us and to supply experts to openly discuss some of their technologies. He is anxious to develop a cooperative program with the U.S. to further develop the Wingship concept. He repeatedly cautioned us to treat the discussions in a confidential manner - I believe he meant that the content of our discussions were not to become public information.

The Admiral noted that Russia has 30 years of experience in developing Wingships and praised the pioneering efforts of Dr. Alekseev (CHDB) in developing the concept. He stated that many other countries have made inquiries about the Ekranoplane but WTET is the first group to receive a formal presentation by the Russians. There are currently no plans to fly the Orlan or the Lun to the USA. I sensed a reluctance to do this even if funds were made available.

When asked for his opinion on the use of wingships vs seaplanes as transport vehicles, he gave a vague response. He stated that the Russian navy supported the Wingship program and the Russian airforce developed the A-40 amphibian seaplane. Both programs were of interest to the Russian government.

3. <u>August 9(PM) President Hotel</u>

Mr. Evgeniy N. Formin, Chief Designer for CHDB, described the long history of this Bureau in designing and building hydrofoil boats and wingships - all under the direction of Dr. Alekseev. He stated that the 400 ton Lun would be used as a rescue vehicle but other missions (undefined) are possible. He made a strong appeal for a cooperative program with the U.S. and was certain that a useful program could be developed. He cited several general areas of possible interest with emphasis on developing

large (> 1,000 tons) vehicles. This may be a reaction to what the Russians believe is the U.S. interest in 5,000 ton vehicles as proposed by Steve Hooker. I believe they would work with us on any size vehicle so long as we provide support for the program.

Mr. Leonid D. Volkov, Head of Aerodynamics Laboratory at Krylov, made the next presentation. He stated that Krylov had been working on wingships for over 20 years and had examined many configurations. Volkov's opinion was that a 500 ton vehicle would be the maximum size if amphibians operations were to contem using PAR. For this large vehicle he would limit the wing loading to approximately 300 lbs/ft^2. The configuration would be a flat wing section between two parallel hulls and dihedral wing sections outboard of the hulls. PAR would be directed only under the flat center section of the wing.

Mr. Volkov's further opinion was that wingships should be small, should not be aircraft, and be operated in sheltered areas. This was based on his considerations of safety and high efficiency. Traditional aviation experience was not helpful in his analysis and he emphasized that new "aero/hydro/dynamic" criteria had to be developed. We need to gather more information on this new criteria to understand what Mr. Volkov meant.

Mr. Volkov proceeded to describe what he believed to be unique Russian experimental facilities at Krylov including special towing carriages; wind tunnels using models tested above fixed and movable ground boards; and mirror-image models. He offered the use of these facilities in any cooperative program.

He also believed that wingships should fly at speeds between 80 and 200 mph; should use PAR; and fly at a height/chord/ratio $\geq$ 0.15 and have an aspect ratio of 2 or 3. This will result in a lift-drag ratio of approximately 16-17 at cruise speed.

During the coffee break I confronted Mr. Formin and Mr. Volkov relative to their contrary opinions on preferred size of the wingship. They both

smiled and stated that compromises could be developed.

Dr. Gallington (WTET team) presented the results of the parametric study of the Lun configuration conducted by L. Malthan of WTET. There were no substansive responses by the Russians.

4. August 10 President Hotel

Mr. B.V. Chubikov, General Director of CHDB, welcomed the WTET and stated he would wait until we met at Nizhny to provide detailed technical information.

Mr. John Reeves, of the U.S. WTET, discussed profile drag reduction for wingships and inquired whether the Russians had been studying the influence of ground effect in reducing profile drag. There were no clear responses at this meeting but John subsequently learned that TsGAI may be looking at this very problem.

Mr. E. Formin, of CHDB, compared the "aerodynamic quality" of 500 mph aircraft with 300 mph wingship in ground effect. He suggested that the aerodynamic quality of the wingship was nearly 50% greater than for the aircraft. The details of this analysis were not provided. He suggested that special engines should be developed for wingships operating in ground effect (not marinized aircraft engines) which would have a SFC less than aircraft engines (again no details were provided).

Mr. Formin suggested that wingships can now be developed for gross weight between 2,000 and 3,000 tons. They would have a cruise speed between 370 and 420 mph; a thrust/weight ratio of 0.20 during take-off and a thrust/weight ratio of 0.10 in the cruise condition. The take-off engines would not operate at cruise speed and attempts will be made to reduce the aerodynamic drag of the shut-down engines.

He mentioned that the Lun has flown 3,000 KM at a height of 1.5 meters above the average of the 3% highest waves. (This is the criteria used by

Mr. Formin when operating in a wave system).

Dr. Chebikov stated there is world wide interest in wingships which will continue to grow into the next century. In his words "the interest is irreversible". In his judgment the wingship should be considered a flying ship to avoid aircraft certification problems. The wingship should always try to operate in ground effect.

Dr. Savitsky of the U.S. team, discussed the importance of selecting a cruise height to avoid contact with the average of the highest .10% waves. If this is accepted, then even the 400 ton Lun would be cruising at altitudes with minimal ground effect. In subsequent discussions it was found that the Nizhny group uses a height equal to 1/2 the average of the 3% highest waves plus 0.10 x chord of the wing.

Mr. Audrey V. Ponomarev, Head of the Ship Hydrodynamics Division of Krylov, discussed several applications of the wingship concept. They included:

- Missile firings from top of Lun fuselage at 300 mph. The drag of the missile launch tubes was excessive so this application was terminated.
- Use as an ASW vehicle. This was the most effective means for searching (area/unit time). Acoustic and non-acoustic devises were used for ASW detection.
- An accident sustained by a Russian submarine motivated the development of wingships as air-sea rescue vehicles. The Lun can carry the entire crew of a submarine.
- Future Russian wingship designs will be more efficient than the Lun.

Mr. Robert Wilson, U.S. member of WTET, presented material on the U.S. PARLAC (landing craft).

Dr. Penetrenov of Krylov indicated that there were stability problems associated with wingships in ground effect and recommended working with the U.S to develop auto-pilot control systems. He would also like to work with the U.S. in developing a mathematical model for all aspects of wingship

performance. In addition he stated that the Russians have:

- a 600 ton ACV
- are developing a 1,000 ton SES

He also recommends building small coastal wingships now and a 1,000 ton wingship as the following vehicle. He believes it is unwise to design a 5,000 ton wingship at this time.

5. Wednesday, August 11 TsGAI, Joukowski

Dr. Anotoli Murin, Deputy Director, provided a summary of the development of this laboratory and its facilities. It was started in 1918 by Prof. Joukowski who died in 1921. It is not unlike our NASA and is equipped with subsonic, transonic, and hypersonic (M = 20) wind tunnels. There are some 50 separate test facilities here including a special laboratory for testing their space shuttle at extremely high and low temperatures. This facility has not been used for the past three years (due to lack of funds). It might be useful to the U.S. which, I believe, does not have such a facility.

The hydrodynamic facilities of TsAGI are located in Moscow and will be visited on August 19.

We were told that TsAGI makes configuration decisions for new designs. later we were told that they make recommendations to the various Russian design bureaus and provide certification for the final aircraft design.

Some interesting discussions were had with Prof. G. Logvinovich, Head of Hydrodynamics at TsAGI (Moscow), when we gathered in a small group. He was very willing to answer detailed technical questions and seemed to have a wealth of practical experience with all aspects of wingship design and operation. I asked whether there was a criteria that TsAGI had which related size and speed of wingship to wave height. He provided us with the following guide:

$$H_{3\%} = \frac{37.5\ g\ \nabla^{2/3}}{V^2}$$

where:

$H_{3\%}$ - average of 3% highest waves, meters

g - acceleration of gravity, meters/sec^2

∇ - displaced volume of wingship meters^3

V - cruise speed, meters/sec

I believe that this equation defines combinations of operational parameters which result in a 4g impact acceleration at the LCG. This acceleration is the average of the 3% highest. Also, I believe he said that their wingships are designed for a 4g impact acceleration and either model tests or the above empirical equation is used to identify the operational sea condition. When the wave heights exceed this limit, the cruise altitude is increased and the beneficial effects of ground effect are substantially reduced.

When asked about a typical drag-lift ratio during the take-off regime, Prof. Logvinovich stated that, in calm water, the maximum value is approximately 0.20 and occurs at 35% of the take-off speed. These values are in agreement with results obtained in tank tests conducted in the USA. Further, this maximum value of drag-lift ratio is similar to that obtained for a high length-beam ratio seaplane such as the Beriev A-40 amphibian. A typical thrust-weight ratio for the wingship varies between 0.25 and 0.30. The wingship values are for take-off with PAR.

In subsequent discussions with Prof. Logvinovich in Moscow, we were told that the drag predictions during take-off are based on model tests. The Russians do not have an analytical method for making these estimates. They feel that spray drag (on endplates, hull, wings and flaps) is a significant but undefined portion of the total take-off drag. Consequently they scale their model results by the cube of the scale ratio to obtain prototype values. They would prefer to scale each drag component separately but, as yet, have not developed such a procedure.

When cruising at an h/c of 0.20, at 400 km/hr, the L/D in smooth water for a 140 ton wingship is approximately 17 and is reduced to approximately 15 when cruising over a seaway. Unfortunately the wave heights were not defined and I believe he was referring to the Orlan (150 tons). The C_{do} is assumed to be 0.02 and the aspect ratio was approximately 3.0.

At lunch I sat next to a Russian hydrodynamicist from TsAGI who had been involved with the development of the A-40 amphibian seaplane. He confirmed that $C_{L_{max}}$ was 2.8, but that take-offs were made at a $C_L = 2.2$. (These were also our estimates). The take-off speed for the A-40 was approximately 105 knots. The cruise speed for the Lun is approximately 200 knots.

6. <u>Thursday, August 12 President Hotel (Moscow)</u>

Dr. Kirill Zozhdestvensky, Chairman of Applied Mathematics at St. Petersburg State University of Ocean Technology presented the results of a linear and non linear solution of the flow around wings and endplates in ground effect. He considered both steady and unsteady flows. In my opinion this presentation was better suited for a symposium on Naval Hydrodynamics.

Mr. Volkov discussed the heave restoring forces, dC_L/dh in ground effect and speculated that this would alleviate the hydrodynamic impact loads. Unfortunately there were no quantitative results presented to substantiate his hypothesis.

Messrs Kravtsov and Kobyzev of Beriev (designers of A-40 located in Taganrog) presented results of a study of "wingship aircraft" which they call Ecranolyat. This concept can operate both in ground effect and as an airplane at altitudes of 1500 to 10,000 ft. When the sea states exceed the design limits of the ecranolyat, it merely flys at altitude. Hence, they see no sea state limit for their designs since they intend to land and take-off in sheltered bays.

They foresee a need for small ecranolyats (~ 25 tons) to provide rapid transportation in the coastal areas of southeast Asia. The cruising speed would be 300km/hr. The configuration would consist of a center-wing section which blend into outer wing panels with moderate aspect ratio. They project a lift-drag ratio of 25-26 when flying at 2 meter height above the water surface. This is a surprisingly high lift-drag ratio for a small vehicle operating at a relatively large height above the sea surface. Since no documentation was presented I would withhold acceptance of this performance.

The Beriev group also presented sketches of possible configurations for take-off weights up to 5,000 tons - all using a similar blended wing configuration and most using a PAR system. All were said to have exceptionally high sea state capabilities - but again no documentation was presented. They state that serious physiological and psychological problems may be experienced by the crew flying in ground effect over waves and suggest that the crews will not fly lower than 15 ft above the water. This will substantially reduce the beneficial effects of ground effect except for very large vehicles. In that case, there is concern that the wake of these large vehicles will upset small ships, yachts, motor boats, etc. In addition, it was pointed out that landing and take-off areas should be cleared of debris before operations commence.

7. Monday, August 16. CHDB (Nizhny)

Vice Admiral Polyanskiy greeted us again and stated he was anxious for a USA/Russian cooperative program to be developed.

Dr. Chubikov (Director) introduced senior members of his staff who were ready to answer our questions. We were then shown a movie which traced the development of CHBD and essentially lionized Dr. Alekseev as the genius behind their hydrofoil and ekranoplane developments. Dr. Chubikov's review of current activities at CHBD were essentially identical to those described in the Francis/Gallington trip report dated June 9, 1993 and hence will not be repeated here. In fact his comments on use of ecranoplanes, certification concerns, cooperative programs etc. are also a repeat of the

material in the Francis/Gallington trip report.

In a round table discussions Dr. Kirillovykh stated that salt water and aerosol intake into the engines is a continuing problem and is being studied actively. He raised all our eyebrows however when he stated that the engines are washed down only once a year. If true, we can only conclude that these vehicles do not operate very often.

We then visited the Volga plant where the wingship Lun (spasatel)was under construction Dr. Gallington reported that there was little progress in construction since his visit in June. Unique features of the configuration are also contained in his June trip report. I attempted to closely inspect the hydroski but was ushered away by CHDB staff who stated this was a CHDB proprietary design feature. Perhaps they are not aware that hydroski applications on water based aircraft were tried by the U.S. Navy some 25 years ago! I did notice that the bottom skin thickness of the hydroski was approximately 1 inch.

During our inspection of the Lun, I stood on the port wing with Dr. V.V. Sokolov, Chief Designer at CHDB. He was most forthcoming in answering questions concerning the Lun design. Specifically:

- The hydrodynamic impact acceleration at the center-of-gravity is in the range 2.3 to 3.5g when landing in waves.

- There is a factor of safety of 1.8 applied to the hydrodynamic load so that the design impact acceleration is in the range 4.1 to 6.3 g.

- The maximum lift drag ratio during the take-off run is approximately 5.0. In the cruise condition, at 270-300 mph, the lift drag ratio is 17 but reduces to 15 when cruising over waves. The take-off and landing speed is approximately 160 mph in 3.09 meter ($H_{3\%}$).

- They are currently designing a 125 ton passenger wingship which will operate in sheltered waters at a speed of 240 mph and expect a

lift-drag ratio of 25 at cruise in calm water and 20 in a wave system where $H_{3\%} = 1.25$ meters. This craft will not have aircraft capability and will not "fly" at altitude. Thus it is a true wingship.

• When operating in a wave system, the height of the wing above the level water line is usually:

$$h = \frac{H_{3\%}}{2} + 0.1\,c$$

where:

h = height of wing above level water line

$H_{3\%}$ = average of 3% highest waves

c = wing chord

• When asked about the many steps on the hull and wing he said they were necessary to assure flow separation when in the take-off mode. They do increase the aerodynamic profile drag - but this must be accepted.

8. Tuesday, August 17, 1993 CHDB Air-Test Complex

We traveled by hydrofoil boat from Nizhny to the CHDB test area located on the Gorky Sea, which is actually a man-made lake on the Volga river. There we witnessed flying demonstrations of the STRIZH and VOLGA II.

The STRIZH is a 1.6 ton vehicle, has a wing span of 6.5 meters and an aspect ratio of 3. It is powered by two 135 hp rotary engines and driven by two inclined shaft propellers which provide PAR and propulsion. The wings are end plated. It appeared that there was approximately 2 ft of wing clearance when flying in ground effect. Data on speed, lift-drag ratio, clearance, sea state capability were not available. Perhaps other members of WTET were able to obtain such data. The STRIZH made several passes in ground effect and also climbed to altitudes of approximately 50-100 meters as it flew by. It appeared that the acceleration of the craft was very low from the at-rest condition to the cruise condition.

The VOLGA II is strictly a ground effect vehicle with no flying capability. It's elevators are locked at all times. It flys at less than 1 meter above the water surface and is truly a ground effect vehicle with little or no sea state capability. There are three sealed inflatable bags under the vehicle - one at each wing tip and one under the centerline. Two ducted fans provide PAR and propulsion. The craft made several passes in the vicinity of the observation catamaran upon which we were stationed. It then climbed up to a beach under its own PAR and settled on the inflatable bags. The bags had closely spaced transverse flow separators to assist in take-off.

We were able to inspect the VOLGA II but not the STRIZH.

After lunch we visited the Chaklov museum. Valery Chkalov made a 63 hour non-stop flight from Moscow to Vancouver, Washington in 1937. His aircraft was on display and an enthusiastic and well informed guide walked us through the museum and aircraft.

9. Wednesday, August 18. Kremlin, Nizhny

Dr. Sokolov provided an overview of the place of wingships as a transport vehicle. He used large charts, which were obviously prepared for previous presentations. No copies were available to the WTET group although Dr. Sokolov said he would provide them during Phase II. The material on the charts appeared to be of a very general nature - more or less an introduction to wingships. Some important conclusions were:

- Wingships are designed for hydrodynamic impact loads. The hydrodynamic sea sitting loads are much smaller than the dynamic loads.

- He recommends a joint development program to define the dynamic loads and pressures.

- Dr. Sokolov's designs all have basically inherent stability (without control systems). The Orlon and the Lun designs do however provide heave damping through a simple control system.

• Relative to materials, CHDB is working to develop new alloys of lithium, cadmium, magnesium and aluminum. If successful, they can reduce the structural weight fraction. At the moment they estimate the structural weight fractions of the Orlan and Lun to be approximately 35%.

• Relative to engines, Sokolov recommends that special engines be developed for wingships. These should have good efficiency at low altitudes and be relatively immune to the salt water environment.

• In the past, research was driven by military needs. Future research should be directed to commercial and civil applications.

• Relative to wingship configurations he suggests that a 500 ton vehicle would have a classical airplane layout; an 800 ton vehicle would have an aspect ratio between 4 and 6; a 1,000 to 3,000 ton vehicle would be an integrated wing-fuselage (flying wing) have a chemical fuel propulsion system a thrust-weight ratio of 0.25 and a maximum of 10 engines. A-5,000 ton vehicle might be nuclear powered - but he believes this to be environmentally unacceptable. I believe all his vehicles would have some degree of PAR. He estimates that the large vehicles (undefined) would have a maximum lift-drag ratio of 25 in the cruise condition in calm water. This will reduce to 20 when flying over 3 meter waves. He also estimates a maximum lift-drag ratio during take-off in calm water to be approximately 7.0.

• He recommends that if new wingships are to be designed and built, we should start with perhaps an 800 ton vehicle and slowly proceed to the 5,000 ton vehicle if necessary.

• The recent crash of the Orlan was due to pilot error and was unrelated to the basic design.

We then broke up into small discussion groups. Savitsky, Wilson, and Czimmek represented WTET and joined Narytsin, Dcen, and Kurnetsow of CHDB to discuss seakeeping and structures. We learned that the Lun was designed for

3g hydrodynamic impact during landing. In the 170 mph cruise condition, 0.2g was recorded when striking the tops of 3 meter waves. The pilots are instructed to increase altitude the moment the keel or endplates strike a wave. Thus, there is constant attention to clearing the waves at the expense of reduced performance.

- The peak bottom pressure recorded on Lun was approximately 300 psi during landing.

- The structural weight fraction of Lun was 34% and the empty weight fraction was 50%. Thus the payload and fuel together were 50% of the take-off gross weight which is 350 tons. The take-off gross weight of the Orlan is 125 tons.

- It will take 5 years for CHDB to design and build an 800 ton wingship. This configuration would have a central flat wing with dihedral extensions on each tip to result in an aspect ratio 4-6. The second generation wingship weight > 800 tons would have a flying wing configuration.

- Engines having thrust capabilities of 30-50 tons must be developed.

10. <u>Thursday, August 19, TsAGI (Moscow)</u>

We visited the towing tank at TsGAI, Moscow and met with Prof. G.V. Logvinovich, Dr. Macionca (?) and Prof. Moslin. There are 850 employees in this facility which consists of four basic departments. Aerodynamics, Aviation/Acoustics, Hydrodynamics, and Scientific Information.

They are looking at the design of an 1100 ton wingship which will cruise at 350 mph, have a range of 6,000 km; cruise at altitude of 5 meters, have a wing loading of 130 psf; and a lift-drag ratio of 26-30. The payload would be 400 tons. They will cooperate with other Russian design Bureaus to develop a new wingship which will satisfy all parties. There was no sign of competitiveness among the various groups - nothing but a spirit of cooperation

The TsAGI tank does not have an irregular wave maker capable of generating specified spectra. Their regular waves have such poor quality that, after running the wave maker for a long time the waves become irregular! We should examine the results of the TsAGI rough water model tests with some caution since, if I understand what was said, their irregular waves are not defined in accordance with standard wave spectra.

I had an opportunity to review the results of Russian calm water model tests of the A-40, Beriev designed, amphibian seaplane. A 1/10 scale model was used. Their lift-drag ratios and trim angles obtained during take-off agreed very well with predictions I presented at one of WTET meetings. Also, the lift-drag ratios for the PAR assisted Lun were approximately the same as for the A-40 during take-off in calm water.

11. Summary

- Although the Russians were cooperative, we did not receive copies of their presentation or docmentation of performance estimates. Whatever quantitative results we did extract from them were usually through private conversations while working through a translator.

- The performance of their present wingships (Orlan, Lun) were not particularly impressive. They all promised substantial improvements for wingships greater than 1,000 to 3,000 tons but no documentation was presented.

- It is difficult to judge the status of their technology since no details were presented.

- Because of their inadequate model test procedures and limited full scale experience (again no details were provided), the performance of wingships in realistic irregular seas cannot be properly evaluated at this time.

- It appears that the Russians would prefer to design true wingships

(always in ground effect, with no aircraft capabilities in order to avoid certification problems).

- The areas of application for wingships are still vague especially if operation over realistic sea conditions is required.

- If aircraft capabilities are to be incorporated into the wingship design, then comparisons with large seaplanes must be made.

- The concept of a 5,000 ton wingship is a far term project which even the experienced Russians would prefer to postpone until they have experience in designing and building 1,000-2,000 ton craft.

12. Recommendation

If there is a Phase II to this study I would suggest that we contract with them to undertake a point design of a 1,000-2,000 ton craft. Their deliverables should include documentation of all predictions including smooth and rough water performance, weight fractions, range, materials used, propulsion systems, etc.

Prior to such a recommendation it is essential that the U.S. establish a need for such a vehicle using present performance estimates such as developed in the WTET parametric study.

DAVIDSON LABORATORY

Daniel Savitsky
Professor Emeritus

FLIGHT TEST
- Flight Controls -

O All Flight Controls ANALOG

O HYDROSKI

- ORLYONOK - deployed 400 mm (T.E. down) during takeoff
  - deployed 500-1500 mm during landing

- LUN - not deployed on takeoff
  - deployed 1500 mm during landing

30 AUGUST 1993

FLIGHT SEQUENCE

- Takeoff Conditions -

- O Wind Limit: 20 m/s
- O Wave Height Limit: 2.5 m
- O Cross Wind Limit: 5 m/s
- O Visibility: Zero/Zero

FLIGHT SEQUENCE

- Taxi & Start-up -

- On LUN, Two outboard engines for Taxi
- At idle, two outboard engines produce thrust for 5 km/hr
- On Lun, two 240-hp APU can provide symmetric auto-cascade engine starts
- Pilot controls thrust of 8 engines with 2 levers for port & starboard banks

30 AUGUST 1993

FLIGHT SEQUENCE

- Takeoff -

- O Apply 20% thrust to reach "tens of km/hr"
  Flaps set to zero, nozzles straight aft
- O At "tens of km/hr," apply full thrust, elevator to neutral
  Nozzles to slightly over 20 degrees down
- O Torque provides nose-up moment
  Full-forward stick to compensate
- O Pilot flies optimum pitch attitude (nominally 4 degrees)
  Gradual elevator movement to maintain attitude

FLIGHT SEQUENCE

- Takeoff Continued -

- O Flap Settings: 10 degrees at 100 km/hr
  15 degrees at 150 km/hr
  20 degrees at 200 km/hr

- O Flaps have 45 degrees of maximum travel
  i.e. full flaps allows 25 degrees of flaperon

FLIGHT SEQUENCE

- Flight -

- O In flight, pilot controls 10 % of travel capability (4-5 deg) but pilot can override if necessary
- O Maximum Turn rate: w/o banking - 1.2 min to turn 180 deg
- 4.5 min to turn 360 deg
: w/ banking - 2.5 deg/sec
- O Out of water, IGE, LUN can go full throttle without reaching a speed restriction
- O Level OGE max speed for LUN approaches Mach 1

30 AUGUST 1993

FLIGHT SEQUENCE

- Flight -

- O Compressibility issues are controllable at Mach 0.5 (Probably at 3000 m altitude)
- O Flight regimes of 240-500+ km/hr are comfortable and controlable
- O In smooth air, is possible to maintain 1 meter altitude at 450-500 km/hr
- O Cruise speed for LUN is 450-550 km/hr
- O Lun can fly on 4 engines can be all 4 on one side

30 AUGUST 1993

FLIGHT SEQUENCE

- Landing -

- O Max Speed for full flaps is 350 km/hr
  Can impact waves with no damage
- O Lun hull designed to touch waves at 450 km/hr
  Flaps up, hydroski down
- O Lun is designed for 270 km/hr landing speeds,
  but this does not drive the LUN design
- O Only hydroski touch at 270 km/hr, hull touches
  at much slower speeds (implies takeoff at/below 335 km/hr?)
- O CHDB recorded 2-g loads for hydroski in 3.5-m waves
  from strain gauges in open seas

30 AUGUST 1993

FLIGHT TEST

- STRIZH -

- O IGE, STRIZH can be trimmed to fly stable over smooth or rough water
- O OGE, its a 50/50 proposition whether STRIZH can be trimmed to fly stable
- O For deviations OGE, and small re-entry angles, STRIZH has a self-leveling capability (i.e., hands off)
- O No stall tests were conducted on the STRIZH

30 AUGUST 1993

FLIGHT TEST
- STRIZH Continued -

- O STRIZH has Dutch-roll damping (tends to drop a wing)
- O STRIZH has high degree of sideslip capability but limited by engine
- O STRIZH is designed for 10 m/s cross-wind takeoff but will do better in real life

30 AUGUST 1993

FLIGHT TEST
- Certification -

- O Only An-40 & An-42 currently certified for international certification
- O CHDB started to investigate civilian certification only in the past year
- O International certifying body regards the ekranoplans as ships

30 AUGUST 1993

DISCUSSION OF WINGSHIP APPLICATIONS

Meeting participants:

Francis, Logvinenko, Covert, Chubikov, Malyshev, Baranov, Sokolov, Fomin, Snyder

Looking at wide range of potential applications

Rescue

Passenger service

Urgent Cargo Delivery

Combatant

DISCUSSION OF WINGSHIP APPLICATIONS

Rescue

- Air/Sea rescue system
  - Five sets of AN-225/Orlon configuration
- Environmental response

DISCUSSION OF WINGSHIP APPLICATIONS

Passenger Service

- Fishing ship crew exchange
- Oil rig service
- Inter-island service
  - Hubs at Singapore, Japan over land remote

DISCUSSION OF WINGSHIP APPLICATIONS

Urgent Cargo Delivery

- Fresh fish to market quickly

- Strategic lift

DISCUSSION OF WINGSHIP APPLICATIONS

Combatant

- Cruise missile carrier
- Amphibious assault
- Surveillance

Special

- Shallow water mining

DISCUSSION OF WINGSHIP APPLICATIONS

General Comments

- Efficient for use in remote areas
  - Swamps, Tundra

- Availability considerations
  - Need 3 to have 1 ready

- Chubikov thinks 250 pax is best size, fwd ramp door is best for cargo, fueling is no problem

- Navy ap[plications imply about 450T GW

- Research indicates 800T is largest useful

WINGSHIP MISSION UTILITY ANALYSIS

Propose to analyze point design(s) taken from L. Malthan's parametrics

Compare to current aircraft, ships in strategic lift

Investigate potential merit as quick response combatant for littoral warfare

Use cost constrained approach and calculate MOE's for all vehicles; reverse calculate to define cost region where wingship would compete

PROPOSED POINT DESIGN PARAMETERS

800T Gross Weight

PL/GW = 0.2

PLW = 160T

WE/GW = 0.44

WE = 352T

Fuel = 288T

Range = 2350 NM

Massachusetts Institute of Technology
Department of Aeronautics and Astronautics
77 Massachusetts Avenue
Cambridge, MA 02139

TELEFAX MESSAGE

TO:	FROM:
Michael Francis, Lt Col USAF tel. (703) 696-2377 FAX # (703) 696-2206	Eugene E. Covert tel. (617) 253-2604 FAX #(617) 253-0051

DATE: 9/13/93 *TIME:* 10:15am

MESSAGE:

Mike, here is a copy of my trip report sorry to be so slow about it I hope it is useful anyway

Gene

TOTAL NUMBER OF PAGES (including this sheet): 10

Memorandum

To : WTET File
From : E. E. Covert
Subject : Visit with Russian WIG Engineers
8/9/93 to 8/20/93

Date : September 12, 1993

This report will follow the chronological order of events.

8/9/93 AM Visit with Vice Admiral V. A. Polyansky

He emphasized the importance of a cooperative effort as a matter of policy between the CIS and the USA. He gave an historical outline of WIG activities. He discused the importance of understanding the "proprietary" nature of the technical exchange (note that proprietary was my word, but I am sure that is what he had in mind). He discussed the valuable role the WIG could play as an international rescue mission. He mentioned the role that could be played in rescuing submariners several times.

Captain Andrei Logvinenko explicitly pointed out that outside discussions would be sufficient to cancel the technical exchange between us and their technical experts. Captain L.. pointed out the Navy was very interested in the WIG, and that since the US was also expert in that area, he hoped that the Russians would also benefit from the discussions as well as the US delegation. There was a considerable questioning on the requirements for the KSM, which were generally answered by a stock phrase "That will be revealed in your discussion with our experts."

8/9/93 PM First general Session

LtCol Francis explained why we were there. That is we were sent to evaluate the state of the art for WIGs and for sea planes. He noted that this survey was "Phase 1", and the outcome of Phase 1 would govern if there was to be Phase 2.

In Chubikev's absence, the Russian presentation was given by Professor Logvinovitch. He was very knowledgeable, and summarized the Central Hydrodynamic Design Bureau's (CHDB) research, which he said was based upon trial and error; using flight test, as well as wind tunnel and towing tank research. He noted a towing tank was built for this purpose. He briefly discussed a proposed 5,000 tonne freighter that could fly at 500 kmph. Finally he disscussed the use of "Lun", a 400 tonne vehicle, as a rescue vehicle.

After a break, Dr Gallington discussed applications for a WIG, and the technical difficulties we forsaw. Finally he presented the outcome of our parametric studies.

Professor Volkov of the Institute named after Krylov then offered some comments. He said that he had 20 years experience in WIG research. His salient points were as follows:

1. They tested many configurations, but only a few were built,
2. Originally they felt a low AR Sea skimmer was the best config.
3. The aero properties correlated with h/c so a large chord (c) implied a

4. Even though WIGs have a low AR, their performance is comparable with best A/C. This geometry implies a better payload to gross weight at take-off fraction. However as the size of the WIG increases, the evolution of the configuration is towards a flying wing.
5. The effects of PAR are favorable because the wing gives lift at zero speed. This implies lower loads at low speeds. However PAR is costly, must be restricted to low speeds, and moves the center of pressure aft. This can cause center of gravity and center of pressure problems.
6. PAR is particularly effective if only the center of the wing is "blown".
7. Wing loadings for large wing ships are high, greater than 1500kg/m*2. This kind of pressure can only be developed by a jet engine. (If I did the conversion correctly, this is over 300 pounds per square foot. Smaller machines can have wing loadings as low as 20 psf).
8. They found aero people don't understand the importance of h/c; near the ground (screen was the word the translators used, but by context the meaning was ground) h/c is more important the angle of attack. they did use aero methods to calculate resistance (drag).
9. They flew at h/c = .16;

8/10/93 General discussion continued; AM

Volkov started the morning by stating that drag was the sum of friction, wave drag, drag due to lift and spray drag.

John Reeves gave his presentation of his drag analysis.

Dr. Fomin of the CHDB discussed the merits of the WIG as compared with other vehicles. This sales pitch included statements of L/D that compared with modern civil transports. He was bullish on the 5,000 tonne machine.

Prof Volkov said that Lun flew at 550 kmph and at an L/D of 25. (If I did the sums correctly VL/D = 8600. A 707 has a VL/D = 9900). He also said the wave drag was less than 5% of the total drag when the speed exceeded 200 kmph.

Ponomarev, also of Krylov, discussed the issue of stability, particularly the stability with respect to height above the ground. The need is for good math models, which implies a need for better test facilities. He also noted there was no need for a 5000 tonne machine. He said the US has a problem, every thing must be the biggest, even if it is not wise. Upon questioning he said a scale up of three was as large as he would feel comfortable with. He also said that he preferred natural stability, rather than augmented stability.

8/10/93 PM

Bob Wilson presented some pictures of the activities at David Taylor Model Basin. He noted WIG's have stability problems. His description sounded like porpoising to me.

Professor Kirill Rozhdestvensky, Head of the Mathematics Department, St. Petersburg Marine Technical University, gave an outstanding lecture on the application of asymptotic methods to the WIG problem. He generalized the Barrows-Widnall results, and was able to use the physics of the problem to show why a particular characteristic length was important for each aspect of the solution. Because his methods required the angle of attack be much smaller than h/c, eg, the angle of attack is less than a degree, if one uses Volkov's value for optimum h/c. Thus the

results did not have much application to the WIG as they used it. Still and all, this was part of their effort and thus relevent.

Dr. Formin noted Spacetel/Lun used a standard engine that was "marinized", but the cycle was not adjusted for sea level operation. He said that for all all gross weight at take-off of greater than 1,000 tonnes the WIGs were superior to aircraft. He said joint studies by Krylov and TSAGI indicated very large WIGs, 2,000 to 3,000 tonnes were superior to conventional aircraft. These large machines would have a L/D greater than 30, and would fly at 600 - 700 kmph. (There were no hard data presented that would support his claims.)

Dr Savitsky than pointed out a contradiction in his data, and finally Dr. Fomin noted he was talking about flying over waves that occurred 1/3 of the time when h/c was 0.1 to 0.15. Questions about long flights, greater than 3,000 km were to be answered later.

Mr. Czmek asked about materials. Dr. Fomin answered that they had used Al-Mg alloys,but that new materials would be better.

Dr. Chubikov said all these matters would be discussed when we got to CHDB. He also said we should keep in mind the WIGs are ships and not aircraft.

Following the break
Gallington raised questions aboout specific problems not discused in the literature. Gera raised the issue of stability in a velocity gradient, and Savitsky raised questions about flying over the open ocean as a function of sea state. and the loads the bottom of the WIG and its tip plates might face.

Savitsky said that if one applied sea plane experience, if the "Wingship" flying over a sea state 5, and must clear a wave that occurs once in a three waves, the altidue of flight must exceed 3.1 meters. A Wingship of chord 3.0 meters would then be flying at a value of h/c of slightly greater than one. The ground effect would not be very large under these cconditions, which implies a low lift-drag ratio.

Savitsky then used seaplane landing conditions to estimate the loads due to these wave impacts. He concluded the loads could be as high as 6 to 8 g's. He noted this is slightly configuration dependent since the loads were a function of the flight path angle and the slope of the wave.

Dr Chubikov said all these questions would be answered either in CHDB or in Phase 2.

Gera asked question related to his research in the area of flight near the ground in the presence of wind shear. (He got the same run around in place of an answer.)

Rozhdestnensky noted that in the 1960's the central laboratories reported a need for a research phase for naval use of Wingships.

(I sensed the Russians felt confident there would be a Phase 2 almost no matter what we said.)

8/11/93 Visit to TSAGI at Joukowski.

Dr. Munin gave a summary of their experience with Wingships.
He noted that they used the Albatross experience to evaluate the problems

of spray. These tests were conducted in a towing tank, by towing a model behind a boat, and through use of radio controlled models. He also noted that at low speeds the induced boundary layer on the surface had a big effect on the performance. He discussed turning performance; it is better to zoom and make a coordinated turn than to skid. He said Wingships would be certified as aircraft not ships. He noted that at very low values of h/c (0.01) and low angles of attack, the lift was primarily due to lower surface over pressure. He said the cruise speed was limited to six times the take-off speed without PAR. Finally, he offered arguments that contradicted to Dr. Fomin's conclusion. Munin concluded an aircraft is superior to a Wingship because the reduced density at altitude reduced loads at high speeds. He felt that wave impact loads would increase the structural weight fraction, and this would be a serious problem for the designers. He concluded by saying that the problems of landing, beaching, mooring, and the like had not been seriously considered.

The facilities at TSSAGI were very good from a geometric point of view. The structure was comparable to our methods. The material choice was not so happy. Every facitilty seemed to have a rust problem, even their fancy new trisonic tunnel. Their understanding of errors was good, but their instrumentation was primitive. Private discussions with Volkov, Rozhdestvensky, and Logvinovitch, were illuminating, but did not add much to my knowlegde of CG travel, weight fractions, or engine performance. I was told that would be revealed during our visit to CHDB in Ninzy Novgorod.

8/12/93 General discussion continued; AM

Rozhdestvensky continued his discussion of asymptotic theory of Wingships. He discussed tip effects and artificial effects of controlling vorticity; including the use of jet flaps. He noted the beneficial effects of a very low zero-lift drag on the maximum lift/drag ratio. He also said the ground effect was very powerful, and this explained why aircraft tended to float while landing. (I believe this is only true when the flight path angle is very small because this angle must be small compared with h/c, which is itself small for his theory to apply. Otherwise his statement needs closer scrutiny. I later told Burt Rutan I did not remember floating while landing a man-powered airplane. If Rozhdestvensky's statement were universally true, I would think sailplane pilots might be aware of thhe feeling)

Upon questioning by Rutan, Rozhdestvensky said they had not compared theory with model or free flight data.

Upon questioning by Savitsky, Rozhdestvensky said he did not feel the unsteady loads caused by flying over waves would be important.

Volkov discussed the general thoery of ground effects, following Prandtl's approach. That is he started with a horseshoe vortex model with an image in the ground. As the height above the ground decreased, the first effect was to reduce the induced angle of attack, and hence the induced drag. As the height above the ground decreased, the image of the bound vortex became more important. He said this was a negative effect, but that this negative effect was balanced by the trailing vortex pair if the aspect ratio was in the range of 2 - 3.

There followed a discussion of the value of the change in the lift coefficient with respect to the height as a function of height.

8/12/93 Group Caucus.

Roger Gallington defined the areas of technical uncertainty.
These included "What is the purpose of our evaluation?"
Requirements
- Evaluate today"s technology
- Project results from baseline of today's technology if new technology were to be used, ie could a long range be achieved with current configuration and new materials?
- Is there merit if an added operational requirement like take-off and landing in the open sea were added?

Measures of Merit
- Type of application
  - Heavy lift, long range
- Service life
  - 3000 hours; 20 years; 500 hour engine life
- Performance
  - cruise range
  - taxi range

Other factors were discussed.

Mike F. described his view of the issues to be faced, including reminding the Russians why we were here.
Hal Fluk asked "...if there was a pony in the pile?"

8/12/93 PM Beriev Design Bureau on Sea Planes

V. H. Kravtsov Head of Design A-40 Albatross
He said they had 10,500 hours of wind tunnel testing anad 5,000 hours in towing tanks and test basins. He claimed that for weights less than 120 tonnes seaplanes or amphibians were better performers than Wingships, while above that weight the contrary was true. (This statement caused a lot of confusion. I was never satisfied with what was implied, and what assumptions underlaid the statement. I think Rutan finally figured it all oout.) The conclusion was that for GWTO weights of 300 tones or greater the Wingships would compare favorably with modern jet transports.

Kravtsov then said his preferred mode of operation was to use ground effect in the take-off and acceleration mode, and then climb to altitude. This is about the first 40 - 50 seconds of flight.

He said he felt the design and construction of a big Wingship should be an international activity, involving GB and Fra as well as the US and Russia. He said that this would also involve the aircraft and ship builders acting as part of the team. Part of the reason for this was the design of the lower part of the hull to with stand the loads.

After a brief discussion of PAR and take-off, Eric Lister asked about fan duct after burning for thrust augmentation at take-off. The answer was that they had not considered it, but it sounded like an interesting idea.

8/13/93 Visit to Yakolov Design Bureau

We talked with Mr. Gustovoy, Chief Designer and VP Marketing, and Messers Dolzhenkov, Popovich and Naryshkin, Chief Designer, designer and program manager for the Advanced Trainer Program. This is a nice advanced trainer. They were sounding us out about the possibility of selling this machine in the United States. I think. We also talked about

their project the Yak-141B, a supersonic VTOL and STOVL. This too looked like a nice machine. I was impressed by the knowledgeability of these engineers. We also visited their museum. While their design areas may have been in the same or adjoining buildings, we were told the manufacturing was done else where. Incidently, we were told their company had just been converted into a stock company with the employees holding 49% and the government holding 51% of the stock.

8/16/93 Visit to Central Hydrodynamic Design Bureau (CHDB) Ninzy Novogorod. AM

Mike Francis reminded them why we were there. Admiral Polyanskii welcomed us and said we were going to get a full exchange of data.

Dr. Chubikov welcomed us and gave us his "vision" speech. He gave us the hstory of the CHDB and its products. The concept of the Wingship grew from the realization that the performance of hydrofoils as a transportation vehicle was limited (L/D < 12 or so.) (Their hydrofoils were very good, and are used world wide. Chubikov said his goal was to build 2-4 Wingships, a family whose size would vary from 5-5,000 tonnes.

We then saw a PRO film. We were all touched deeply and re-upped on the spot. Their conference room had a nice display of the various vehicles they had built or hoped to build. I believe Jim Camp took pictures of all the posters and some of the models.

We then toured the Lun construction area. The Lun is a large machine, comparable in size to a 747 or a C-5B. Its construction strongly resembled ship building practice with a lot of welding and with many smalish compartments. The entrance and exit hatches to each compartment looked like water-tight-doors to me. The wings were bolted to the hull with a large number of bolts. The wing carry through structure looked heavy and complex. The hull had 6 or 7 circumferential ridges that were used for spray control. The wings and tails seemed to follow aircraft construction practice. The hydroski, which was said to be used for landing, was enormous, and undoubtedly very heavy. The fittings and hydraulic cylinders were massive.

After a tour of the construction of "Lun/Spacetel" we had lunch.

The we all gathered in a conference room and questioned a designer. I did not get a card so he will remain nameless, although I believe his name was Killovykh, or something like that. He seemed to be knowledgable.

1. The fuel is in the wing, with the center of volume at the CG, so fuel transfer is not needed to control CG position. The CG location would be revealed in Phase 2. The answer to the question "Was the fuel volume selected to meet payload/range requirements?" was "That is classified."

2. They used tempered aluminum alloy for the structure, but knocked down the allowables by 33% or so because of the loss of strength caused by welding .

3. In answer to Joe Gera's question, the pilot selects the angle of attack, usually at the ideal value, and the altitude is controlled by the flight speed.

4. In answer to Dieter's question, they designed to avoid fatigue. This means they kept the residual stress low to reduce stress corrosion to a

level where it could be controlled by anti-corrosion techniques.

5. In answer to Bob Wilson's question, the design limit was not set by sea keeping, but they did check the sea keeping loads and the strength was addequate. There followed a general discussion, which included the ideas they designed for strength and for fatigue; in many places on the Lun the landing loads were the limit loads; they would not tell us the sinking speed at landing, but said they could land in a 3.5 meter sea at 400-550 kmph. They had landed at 80% GWTO, and had touched waves in flight without damage. (Whatever "touch" meant.)

Finally it came out that the hydroski loads upon contact at 270 kmph caused a 2g load, and this drove the design. The design landing speed was said to be 270 kmpf. They said these loads were measured by strain gauges. They did not answer Dieter's question about factors of safety.

He said they checked aeroelastic effects, and that they did not have a flutter problem. Joe Gera asked if they wingship was naturally stable in roll and yaw? "Yes." They have a wet wing where fuel is stored. They have weep holes. I mentioned the C-141 weep hole and stress corrosion enhancement by the fuel.

Joe Gera asked about the crash of the "Orlon" . We were told it was pilot error, but that was all they would say.

Dan Savitsky asked about engine operation in a salt air environment The answer ws "This is a complex question." Finally a detailed discussion on engine wash requirements. I gathered they use the number of take-offs and landings and not operational hours to determine wash cycles. (This makes sense to me. Once per year might even be the correct answer if they only flew the KSM once per year.)

John Reeves asked why they chose the turbojet as opposed to a fan jet for propulsion. They answered the engine selection was driven by the military mission.

They would not answer the question about elevator power, ie degrees of deflection per g. They said they did not need to use elevator deflection to balance the moment developed by the hydrdoski; they used engine power.

In answer to Bob Wilson's question they said they shut down some engines for cruise, and shut down the inboard engines during cruise.

In answer to Burt Rutan's question, even at 20 degrees of elevator deflection, there was sufficient differential operation for roll control.

In answer to Mike's question Lun and Orlon were cleared to fly one km above the ground.

In answer to Jim Camp's question (and after much shilly-shallying following Mikes question) they said the longest flight was about 4 hours and they guessed they flew 2,000 km.

Burt asked if they had considered used of a vertical fin near the CG to generate side force. This would enable them to turn without a bank angle. They said this was too inefficient to be used.

Hal Fluke's question about the ferry range of Lun was ignored. (They had said earlier that these are experimental vehicles, so operational issues were not known.)

In answer to the question of the reason for termination of the 2,000 flight, they said they had completed the task assigned to the flight. They said the total range was classified. They said they had used a special technique to determine kmpkg of fuel. They would not give a value for that parameter.

They ignored Burt's question on the turning radius of Lun.

I had given Fomin written questions on weight fraction as a function of GWTO. He said these questions would be addressed here. We got no information at this meeting.

8/17/93 Visit CHDB Airtest Complex

This was a tour of a facility a couple of hours up the Volga River on the Gorki Sea. The trip was made of a Hydrofoil. The ride was good, even when crosssing wakesss of other ships. I was impressed with these craft, at least on a smooth river. In adddition to a flight test center, the faacilities included a wind tunnel, an open jet tunnel that looked ok, but had a turbulence level of 0.8 per cent, and a towing tank, which they operated for us. The demonstration of Strizh suggested that it flew a tenth to a few tenths of its chord above the water, and it zoomed to turn. The take-off was very slow. The Volga, a small five-place machine that were selling for low density transport routes, was a real "sea skimmer". Its chord and span were anout 20 feet, and it seemed to fly a foot or so above the water surface. Its turn radius was very large, so I presumed the turn was really a skid.

8/17/93 Evening summary meeting.

Mike said he had met with them and said we want data from flight test, both stability and control, and performance. We also want the accident report on the Orlon. He said they had asked him to get specific questions from us. (I noted I had submitted written questions to Fomin, and had not heard a peep from them.) Mike noted these was no paper at the Lun connstruction site, and wondered if it was an active program. Bob Wilson figured it would take a year to fix the Lun up for roll-out.

Mike suggested we instrument a vehicle for flight, and help interpret the data, which implies a form of coopeation. However the future is not clear.

Dan S. he had seen no data, but conversation indicated the value of L/D was disappointing. The load factor is a function of speed and wave height, maybe 3-3.5 g's or about 1.8 timess design load factor. Burt noted thd hydroski coud be heavier that a landing gear; John Reeves said the compendium said that it was 4% of GWTO.

Bob Wilson said as a prototype Lun was only good for 500 tonnes. Which, if larger is better, implies the need for complete redesign. He said engine development was of first order importance. Composites were of interest and could possibly improve the pay load weight fraction from 10 to 12.5 % of GWTO.

Eric sat down with the engine guy and said the bait seemed to be always pulled back, when an interesting point came along. We agreed that on

8/18 we would have small groups or no discussion at all.

Someone noted that the only thing the Russians possess was flight experience.

People's reactions:
Joe "Strizh flight impressed him.
EEC said in this case the movie was as good as real life.
Roger said obtaining stability in ground effect was a real contribution.
Dan said he saw 1. a real sea skimmer that could not escape from the ground, and 2. a demonstrator both in and out of ground effect.
Burt said the Strizh had the same maximum velocity in and out of ground effect.
Jim asked if we could get the reports Capt Maleshevv hadd reviewed while he was the desk man at the Navy.
Roger said what we send to Congress depends weakly on what we learn here. Coming to Russia has value in developing a base line for parametric analyses.
Roger also said The Technical Experts implied that if the sea state was less than N, they will fly and hit a wave from time to time. Roger said "It looks like Lun is not a long range craft at sea.

Group suggestions. As small group favored each specific item
1. Discuss joint USA-CIS application
2. Conduct joint experimental activites (Flight Test)
3. Conduct joint design efforts
4. Conduct joint studies on structures and sea worthiness.

8/18/93 At the Kremlin Ninzy Novgorod General discussion
AM
The goal for this session were two-fold. First better understanding of how well things are done, aand second identify areas of mutual interest. The Chubikov gave his agenda as follows:
1. Hear Sokolov's report
2. Have lunch
3. Break up into small groups for technical discussions

Sokolov reported on his 30 years of WIG activity.

The WIG program was started because of the limitted maximum speed of the hydrofoil. First theoretical and paper design studies were used to develop design methods , as well as developing a data base. These resultts were promising. Thus they proceded to experimental studies. He gave a detailed sequence of events, ie from paper to wind tunnel and towing tanks, to rradio conttrolled models,etc, etc. With all this data they feltt they needed to improve the L/D to 30;improve the structure.

The three generations of Wingships have GWTO ranges as follows:
1. up to 500 tonnes classical configuration
2. 500 to 1,000 tonnes sub-scale data base, includes a flying wing
3. 1,000 to 5,000 tonnes atomic powered machines.
   Increase T/W to 0.25. Now T/W = 0.15.

A propellor was an adequate propulsor up to 800 tonnes.

The a question and answer period followed. Usually, Chubikov let Sokolov answer, the amended the answer to bias towards the 5,000 tonne machine. In essence Chubikov felt the were no problems in going at once to 3,000 tonnes, just a scale up of Lun, as it were. The very high L/D

ratios pertained to calm sea, In experiments they matched Froude number, and corrected to Reynolds number as aeros do.

The V. B. Dimidov gave a lecture on stability and control, The was a complete presenntation, with lots of formulae, and some numbers. The material was presented on flip charts and went by very quicky. There were 14 classses of problems they solved to get to this point. This was followed by a philosophical discussion of design problems.

Then we had lunch
PM
Focus groups

1. Design
2. Sea worthiness and structures
3. Flight Test, and
4. Application

Application Focus Group
Joint view

1. Rescue at Sea
2. Unique transport (Change crews of ships at sea)
3. High speed bulk cargo delivery
4. Use of Wingship in polar, desert, swamps, ice caps, etc where no other vehicle goes at high speeds
5. Shalllow water, poor harbor freight pick up and delivery

The discussion would focus on an aplication, then Chubikov would disrupt it.

General Comments

The Russians were divided among themselves as to the use and state of development of the Wingships. The division usually followed lines of turf protection.

We did not really get very much hard data or information. What opportunities we had made the data difficult to record either because of the nature of the presentation, on flip charts, or hand drawn viewgraphs or because of the rate at which the material was presented. The latter problem was complicated by the translation.

We did get an occasional nugget that confirmed our understanding, but those were few and far between.

I hope that if there is a phase 2, that either some sort of lever can be applied to get what we pay for, or that we are prepared to walk away and avoid the situation where all will be revealed in phase 3.

WINGSHIP INVESTIGATION

SUMMARY OF NOTES BY BURT RUTAN DURING 9 AUGUST-20 AUGUST 93 RUSSIA TRIP

In general, these observations are limited to areas of flight test, model test and structural issues.

9 August Ministry of Defense - Polyanskii

Research started in 30's accelerated to flying prototypes in 60's. Evolution followed hydrofoils to aircushion to IGE flight (wingships). Missions were purely defensive, no long range requirements. Sub rescue was an important driver.

9 August - President Hotel - Fomin

The KM (Caspian Sea Monster) was built in 5 years (1961-1966). 450 tons, but flew above 500 tons and 500 km/hr.

Volkov - Aspect ratio is low to achieve long chords, since H/C is the important ground effect parameter. The positive ground effect is neutralized due to the overall low aspect ratio. Offset further by wave height. Future vehicles will be flying wings to achieve performance goals. Lun wing loading is above 400 kgm/m2. Large wingships may exceed 1500 kgm/m2.

Accidents were due to pilot error. Flown O.G.E. Then AoA limits exceded, then nosed in. This is a new science, not well understood by airplane people.

Model test methods used: 1. fixed screen, 2. opposing models and 3. movable screen gave best results.

10 August - President Hotel - Fomin

Wingships can compete with C-5, 747, etc. especially when airfields are not available?! There were wide gaps in the wingship development history.

Structures are heavy by aircraft standards, due to multiple requirements and use of materials (aluminum/magnesium) that is only 2/3 the strength of aircraft alloys. Design driver is normally wave impact at takeoff weight.

Largest aircraft is about 1000 tons due to airfield limitations, but a wingship can reach 3000 tons and have L/D=30, although best L/D on Orlionic is about 12. When asked farthest flight conducted on a wingship, answer was 3000 km (did not know fuel fraction). We got referred to the CHDB folks later.

Chubikov - Growing interest, will be the achievement of the next century. All current prototypes have drawbacks, but can fix if we join in international development teams.

Malyshev - wingships are generally land based, but Lun is water based. Antiship missiles fired at 500 km/hour. No undesirable pitch or roll during salvo launch. Lun size can take 150 wounded or 500 seated (sub rescue). Rubber boats can come onto wings while sea-sitting in sea state 4. The Lun is large enough so it doesn't roll in waves big benefit for rescue mission.

Ponomarev - There is a "vertical stability problem" that must be solved before certification (height stability?). In general, they are stable in a small AoA range only.

11 August - TsAgi

Four facilities shown. 40' x 85" elliptical low speed wind tunnel, 2x3m transonic/supersonic tunnel, 30m static load/ heat load/vacuum chamber (Buran) and fighter simulators. Of these, only the low speed tunnel was in use. Lots of dust on the switches! The moving base simulator with the Buran cockpit on one end and a car on the other resembled a bizarre accident. The fighter simulators used a model geometry board with video similar to our early 70's technology. The photo of a Rutan Quickie homebuilt in the low speed tunnel was claimed to be a Ukraine design.

12 - August - Rozhdestvensky

Presentation of fundamentals of design methods for WIG craft. When asked if his performance design methods were verified by the flight test results, he said he didn't know, we would have to talk to the test guys. Apparently the flight test results are not studied by the university professors!

12 August - Volkov

He emphasizes that dCL/Dh is high, resulting in the small reaction to missile launch. Also, the accident. The vehicle was diving 10 degrees, then ground effect reduced the slope to only 1 degree at impact. He didn't say why it was damaged in spite of only 1 degree gamma.

12 August - Krautsov - Berlev Design Bureau

He explained that the A-40 seaplane pilots see 4.5 g at pilot station when operating in 1.7 meter waves. He showed some large (1500 ton) design for WIG. His range summary showed (for smooth seas) that conventional seaplanes have an advantage below 120 ton weight. Above 120 tons, there are advantages to using PAR and WIG for takeoff, but the vehicle should cruise height. He doesn't like ground effect for cruise due to obstacles. He envisioned very large designs would have a 10-15% advantage over current jets if new engines were used. Speed would be limited to 500 kph, though. He reasoned that 3-4 hours would fatigue a crew flying IGE.

16 August - Chubikov CHDB Volga Plant

Comments from the Lun inspection - Only a small team working the vehicle. Possibly just a "look busy" for our tour. I didn't see materials flowing or any drawings/work orders. Also, they seemed to dash for the door as we were walking out. Skin on Hydra-

ski is approximately 28 mm thick and pivot is very heavy. Looks like weight of ski system is similar to a landing gear. Structure is welded plates of aluminum except for flaps, control surfaces and horizontal tail where riveted thin skins are used (like aircraft practice). This prototype appeared 95+% complete structurally, but only 5% of systems installation. We were cut short and were not allowed to look at the forward hull. No photos were allowed. The film "Black Tail of Sagittarius" included interesting footage of flight operations as well as beaching and operating on ice. A good historical review of most of their early configurations. (I hope to get a copy - HINT.)

Chubikov credited Alexaev with the main credit for Soviet lead in wingships. His greatest interest in the big ones. He thinks optimum size is between 1000 ton and 4000 ton. He stated three important items: 1. Market research for most effective uses, 2. Build two to four machines in various sizes, and 3. Certify to international level. (Whatever that is!).

One of the models shown had a main wing with a pivoting camber. The leading edge pivoted up (hinged at about 35% chord) to capture more PAR.

Discussions in Leu of Lunch -

Cg range of Lun is small, almost all fuel is in wings. The inferred that it has natural height stability, and will hold speed and height at constant thrust. Can land in 3.5m waves at 350 km/hour with full flaps. Normal landing speed is .8 times takeoff speed (?). Pilot has an AoA indicator but doesn't use it as much as a normal aircraft. It is stable roll/yaw both IGE and OGE, but IGE is more difficult. They will not say the Cg range now -- only that the acceptable range is smaller than for an aircraft. My guess based on some other inputs is 45$ to 60% chord of the main wing. OGE static stability is fine this far back due to the oversize horizontal tail.

Our inquiries on elevator effectiveness and sensitivity resulted in some limited information:

> elevator/g? = no answer
> elevator required for gusts and big waves? = less than 5 degrees.
> maximum elevator during takeoff? = 20 degrees T.E.D.
> elevator travel in cruise to landing? = "low"
> engine-out controllability? = can survive four failed on one side!

They are "investigating" operating the Lun as high as 1 km altitude. Longest flight by any wingship? Answer = 2000 km/4 hours. This is likely the correct answer, not the 3000 km stated earlier. An early wingship seen in the film has a cg-mounted vertical fin with a flap, for turning at bank = zero. This was not effective and was not tried again. When questioned about turn radius, the answer was "same as conventional aircraft of same weight." Actually, turn radius is a function of speed and bank angle, so I'm feeling misled again. The limited bank angle to stay IGE must severely limit turn capability. The only significant turn I have seen was the Striege operating OGE.

17 August

Visit to test area for flight demonstration Streigh and Volga II and display of tow tank and low speed wind tunnel.

The Streigh was not impressive. It seemed to struggle to get off the water even though it was operated solo. Its IGE cruise also seemed to require a lot of power. Information that follows in this paragraph came from Chubikov during the Streigh demonstration: minimum cruise power IGE is about 60% of takeoff power (note most land-based aircraft can fly on less than 30%). At maximum power, the speed (160 km/hour) IGE is the same as the maximum speed OGE! i.e., induced drag benefit is not noticeable at high speed flight. The minimum power to remain airborne OGE is 50% more than IGE. This doesn't make sense, because it looked like there was a relatively small difference between takeoff and cruise speed.

The Volga II, with its inflatable sponsons, very low wing loading and tiny control authority is more like an air cushion vehicle that a wingship. Its turn maneuverability is poor and it, too, seemed to struggle to get dry even though four if its five seats were empty. They later pointed out that its prime advantage is its use with a low-skilled pilot when operating over ice or brush. (They are building 10 for Siberia).

18 August - Nizny Kremlin - Sokolov

They have studied our questions but won't answer most until next phase.

Hydrofoil boats are limited to 150 km/hour, so in 60's they started with 1.5 to 2 ton wingships. The United States' approach was to reduce landing speed with low wing loading and high-lift flaps. The CHDB instead developed PAR and hydroskis.

All good wingships are stable, static and dynamic. Streigh uses manual control. Big ones use boosted controls with autopilot.

First generation was the 500 ton ~~km~~ KM. Second (design-only) was 1000 ton vehicle. They have powered model test data on this but would not share it. Third generation design was 1000 to 5000 ton and atomic powered. Now believe a practical limit is 3000 ton, but would try 800 ton as a next step above KM. He would guarantee performance at the 800 ton size. He stated that an 800 ton ship would be a flying wing. It would have L/D = 25 to 30 over calm sea and decrease 4 to 5 in sea state 4. Aspect ratio 5 to 6.

Diomidov, the flight controls designer, stated that KM controls were crude. After 86 (Lun) the new autopilots have functioned 1500 hr (Mentor 3 and 4 systems) without failure. All FCS are analog type. He noted the ships are "inobediant to elevator and aileron at low heights."

The cruise turn is a complex maneuver. The aim is to maintain height and speed while using roll, side slip, AoA and thrust in a coordinated way. Early pilots used rear view mirrors to judge tip height. They now have indicators. Future generation designs will be controlled differently, allowing relaxed stability requirements.

18 August - The Flight Test Separate Group.

Participants:

Nickolaevich	Chief Designer, Lun
Pezevozkin	Engine Designer
Diomidov	Flight Controls
Diaduro	Systems
Shozin	Deputy Chief Designer
Petrov	Engine Department Chief
Tomilin	Deputy Chief Engineer
Jim Camp	Dt
Eric Lister	
Joe Gera	NASA
Burt Rutan	Scaled Composites

They Described the Orlionok 1992 accident thus: Pilot entered a turn at 370 km/hr and failed to increase thrust. This caused speed to get too slow - down to 300 km/hr. The ship settled and dragged the inboard tip. Pilot incorrectly responded by pulling the stick aft. The ship climbed to a stall, splashed, climbed steeper, then dived into the water. Cause - inadequate pilot training.

Question - Extent of instrumentation for flight test?
Answer - 2000 parameters, half of them structural, half aero/hydro. Data Reduced in Caspian facility and sent to CHDB for analysis.
Question - Is the Lun envelope fully cleared?
Answer - All points are tested.
Question - Does it meet certification requirements?
Answer - There are no standards we have To create them.
Question - What is your biggest area of concern for certification?
Answer - Safety.
Question - Does design and model test methods adequately predict?
Answer - Yes for aerodynamic, not perfect for hydrodynamic and structural.
Question - How many test hours remain until you have operational suitability?
Answer - Lun already is Ops suitable.
Question - How many years , first flight to Ops suitability?
Answer - Three years.

We asked to be talked through a normal operation of Lun, and got the following dialogue: Taxi, using outboard engines only, results in 5km/hr at idle with zero flap. Taxi wind limits are 20 m/sec (crosswind is critical). Wave limits 2.5 height.

When sea sitting, anchor in nose and weather cocks. Visibility limits for takeoff 300 m. Have <u>not</u> made a night take off or landing. (twilight only). Take off wind limit 5m/sec crosswind (low!) Start at only 20% thrust, all engines, zero flaps and lots of spray until 30 km/hr is reached. At 30 km/hr, advance to full thrust, nozzle down 20 degree when nose raises apply full forward stick (for now). At 100 km/hr apply 10 degree flap. 15 degrees at 150 km/hr. 20 degrees at 200 km/hr. now the stick is forward only 4 degrees

elevator. Achieve liftoff attitude and then full flap - lift off speed classified (chart shows about 250 km/hr thought). Flap can move 45 degrees (at full flap plus full aileron). Auto pilot authority is only 4 to 5 degrees surface travel. Lun uses hydra ski for landing and for rough seas takeoff, not for smooth takeoff. Typical Lun turn in banked flight =2 1/2 degree/sec (1.2 min for 180 degree). Flutter is the limit for V max. Cannot remain IGE at full throttle.

My next attempt to extract some data about relative IGE/OGE performance went like this:
Question - what is a good cruise speed over smooth sea?
Answer - 420 - 500 km/hr
Question - OK, assume 450 km/hr at 1-2 m height. If you now pull up to 100 m height and stabilize without changing thrust, what speed will result?
Answer - Unless you change thrust you cannot climb OGE, but at 10m height, speed will decrease to about 400 km/hr.

Conclusion: This team really needs to inspect some real raw test data. We are depending too much on individual's recollections/estimates.

MCDONNELL DOUGLAS

McDonnell Aircraft Company

5 October 1993

Subject: WIGE Flight Demonstration Trip
Follow-up Information

To: Col (Sel) Mike Francis, Burt Rutan, Joe Gara, Roger Gallington, Jim Camp, Chuck Miller, Ed Parrott.

1. Here are the names of the various individuals that we met on our celebrated visit to Dagestan.

Towns: Mahachkala and Kaspiysk

Region: Dagestan

Deputy Minister of Industry for Dagestan: Shamil Algv

Vice Mayor: Mr. Viceman

Vice Premier of Dagestan: No Russian or American could remember. If you know this please call me and I will distribute information.

Volga Plant Director: Mr. Magomet Ismailovich Gaidarbekn

Dep Director of Security Vulga Plant: Mr. Leonid Tranovich

New LUN Designer: Vladimir Niholayevich Kirillovyikh

2. This is the best data I have. If you have other substantiated inputs regarding spelling please call and I will issue a revised edition to our team.

3. Enjoyed traveling with all of you. As Roger pointed out, it was a good group!!

Frank

Frank Tubbesing
314-234-8912

P.O. Box 516, Saint Louis, MO 63166-0516 (314) 232-0232 TELEX 44-857

GERA

Report on the Sep. 25-Oct. 2 Trip to Russia.

The Wingship "Orlyonok" Demonstration Flight

Six members of the WTET traveled to Kaspiysk on September 28th to witness a demonstration flight of the 120-metric ton Orlyonok wingship. On the afternoon of the previous day the team met the Russian experts who had traveled to the test site mainly from the Central Hydrofoil Design Bureau (CHDB) in Nizhny Novgorod. Also present were the wingship propulsion expert from Kazan, and Dr. Diomidov, the flight control system designer, from St. Petersburg. During this planning meeting the American team reiterated its request from our August meeting with the CHDB for specific details of the demonstration flight, including flight data, and at least one on-board observer from the American side. The latter request was turned down immediately by the CHDB General Director, Boris Chubikov, citing both safety and security reasons. He stated further that an out-of-ground effect flight will not be performed during the demonstration. The Orlyonok had flown to heights u to 80 meters, and according to TsAGI analyses the vehicle should be capable of reaching altitudes up to three thousand meters. Mr. Chubikov promised that the pilot of the Orlyonok would demonstrate stick free stability by disturbing the vehicle from trimmed flight and allowing it to return to trim without any control inputs

The demonstration flight took place on the morning of September 28th in the Russian naval installation in Kaspiysk located on the east coast of the Caspian Sea. According to our hosts we were the first Americans ever to visit their installation. We were taken by bus to the Orlyonok which was parked on a concrete apron adjacent to the water. Weather conditions were overcast sky and fairly brisk winds from the southeast. Later it was reported that the highest wave heights were around 2.25 meters.

All three engines were started while the Orlyonok was still on the concrete ramp approximately 200 meters from the edge of the water. Relatively short time was spent after engine start before the vehicle taxied to the edge of the water using small diameter wheels located aft of the hydroski and on the wingtip endplates. After the vehicle became waterborne, substantial amount of spray was generated by the two PAR engines since most of the thrust appeared to be generated by these engines. During the taxi to a downwind position from the observation pier, substantial pitching and rolling motions could be observed. The magnitude of these motions were large enough to be uncomfortable for potential passengers of wingships of comparable size.

The takeoff appeared to be somewhat laborious with a duration of slightly over 2 minutes. The relatively large amplitudes of the pitching and rolling motions

were decreasing with airspeed. The extent of spray was large enough to envelope the whole vehicle when viewed from the side. Although no quantitative data was made available, the normal accelerations caused by wave impact, especially during the middle of the takeoff run, must have been substantial.

In flight the Orlyonok appeared to have a steady and smooth flight path and looked very impressive. It made several passes in the vicinity of the observation pier, one of them clearly out of ground effect, at an approximate height of 5-7 meters. Because of the distance from the observation pier, the bank angle during turning flight could not be estimated; in fact, the vehicle went out of sight as it turned around for the next pass. As the flight progressed the wind and wave height were increasing.

After a duration of 40-50 minutes the Orlyonok landed in front of the pier with the hydroski deployed. The landing distance between touchdown and completely waterborne state was surprisingly short, and the spray did not look quite as extensive as earlier during the takeoff. After turning around the vehicle taxied back to the initial location and rolled out of the water to a distance of 200 meters. During this operation only the PAR engines were used.

After engine shutdown our team was permitted to take photographs and to examine the exterior of the vehicle. Several large dents were noted on the leading edge of the horizontal tail, and on the upper surface of the left wing. The former was reputedly caused by bird impact. The large number of spray deflectors on the hull and on the wing endplates had complex shapes and must have resulted from many hours of experiments. On the lower surface of the flattened nose cone there were two rectangular dielectric plates aligned with the longitudinal axis, with a row of three smaller circular plates each side of the rectangular plates. Both types of plates were embedded in and flush with the external skin.

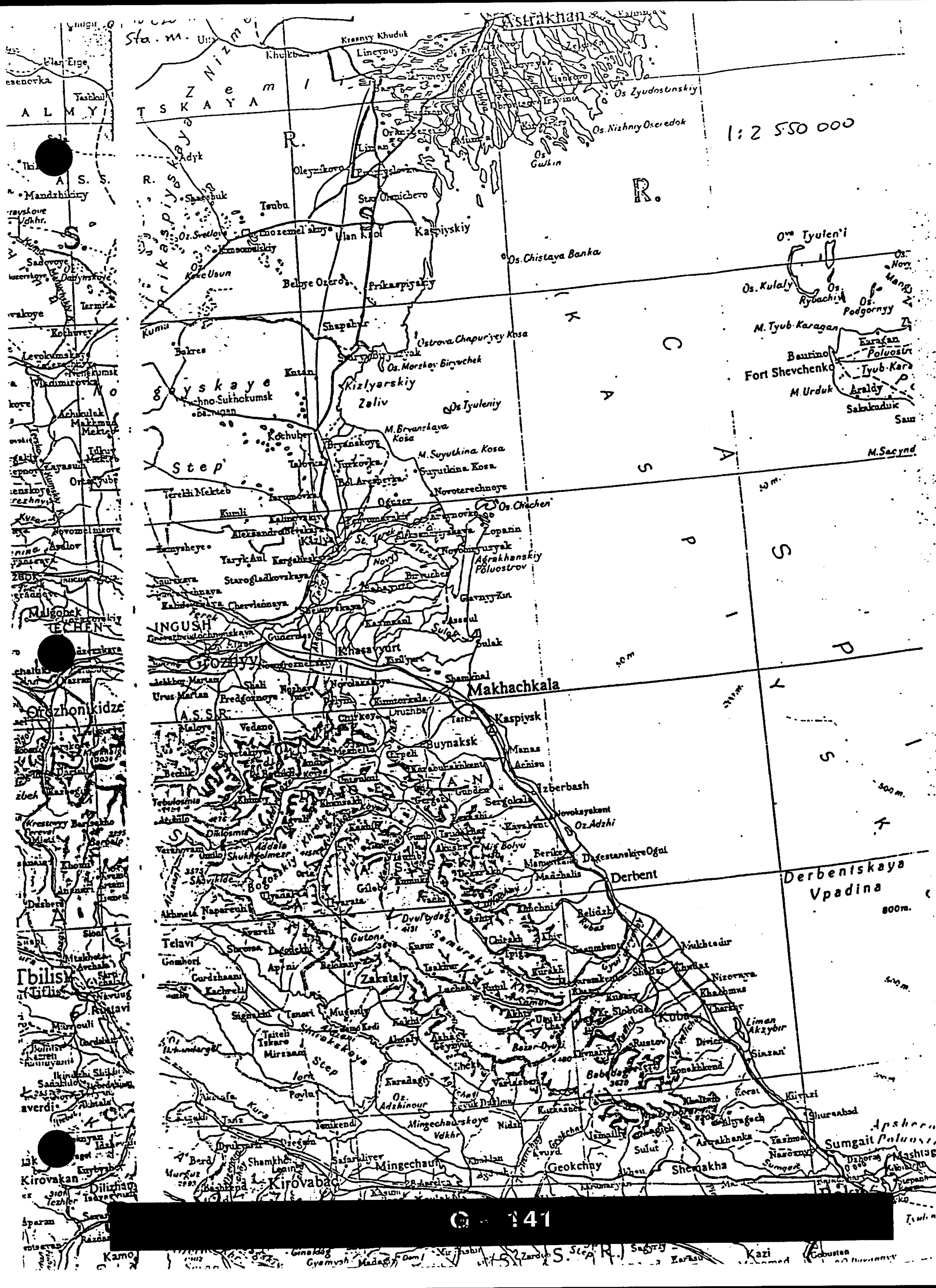
The overall impression of the flight demonstration was that while the demonstration itself was impressive, the American team was disappointed at not being permitted to inspect the interior of the Orlyonok, or given access to time history type data from the flight. At the same time we had an appreciation of the amount of work the Russians must have performed to bring the Orlyonok back to flight status in only a month after a reputed downtime of two years.

During the afternoon the team reassembled in our hotel in Makhachkala for a post flight briefing. The two pilots stated that the flight was fairly hazardous in that the previously experienced highest wave was only 1.5 meters. The 2.25 meter, long length waves on that day could have resulted in water ingestion by the engines and excessive hull impact loads. Because of the higher than normal

wave heights, the flight altitude was maintained at four meters, that is approximately 1.5 meters above the highest crests. The high waves were also responsible for the 220 km/hr liftoff speed instead of the usual value of 200 km/hr. Cruising speed was 360 km/hr; to the question what the stall speed of the Orlyonok was the pilots reluctantly called out the 250 km/hr value. It was obvious that no stall tests had ever been conducted with the vehicle. The pilots also mentioned that during the flight the automatic flight control system was not engaged, ostensibly to get some manual control flight time. This gives credence to the claim that the vehicle possesses stick free stability with the automatic system engaged even though the stick-free stability tests were not performed as requested by the WTET.

During the post flight briefing Chief Designer Viktor Sokolov was very helpful in providing answers to many of the team questions. As to the altitude determination during cruising flight, he stated that there were three measurement techniques used, the preferred one being radar altimetry. The rectangular dielectric plates mentioned earlier serve as the cover for the Doppler radar transmitter and receiver that provides speed and sideslip signals for on board use. The three pairs of circular plates are the covers for similar radar devices that provide triply redundant altitude measurement for display and automatic flight control utilization. The other two measurement techniques include ultrasonic sonar measurement and the use of the earth's electric field strength. For the latter technique, small amounts of radium are place on the lower surface of each wing at a mid span location. The ionized air molecules in the vicinity of the radioactive material allow the measurement of the potential associated with the electric field of the earth. The small amount of current resulting from banking the wingship can be used for roll stabilization. The technique is also known in this country and is utilized in the so-called electrostatic autopilots. In addition to being helpful in answering my questions, Mr. Sokolov wrote down a detailed scenario for the flight operation of the Orlyonok His translated notes were given to Roger Gallington; a copy of these notes is also enclosed with this trip report.

Joseph Gera
(805) 258-3795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M. Urduk
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INGUSH
Khasavyurt
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Shemakha
Sumgait
Apsheron Poluostrov
Mashtag
Shirakskaya Step'
Kura
Samurskiy Khrebet
Babadag
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Kazi Magomed
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[redacted]

Wingship demonstration flight held 09.28.93.

Takeoff weight of the wingship - about 120 tons.

Rough sea, wave height - 1,5-2,0 meters (plus a windwave and choppy sea).

the wave is higher than the regular by 0,5 m.

Wingship characteristics

3.1 Beginning of movement

- starting and cruising engines are in the takeoff mode with a total thrust of 35 tons/second;
  the cruising engine 15 tons/sec, the starting engines 10,5 x 2 t/s.
- the nozzles of the starting engine are in horizontal position, i.e. the engines work to produce thrust (without flowing under the wing).
- the flaps are retracted.
- the hydroskies are extracted and are in the starting position (that is 20-60% of the full extraction and and the full extraction is 1,5 meters (depending on the sea state)).

3.2 When the wingship reaches the speed 50-70 km/h the nozzles are brought to an angle of +15° with flowing under the wing.

3.3 When the wingship reaches the speed of 150-180 km/h the flaps are gradually turned to the +20° position.

1. At the speed of 200-230 km/h the takeoff from the water surface occurs, and when the speed reaches

mo ces

becomes horizontal, the flaps are gradually retracte
and the wingship is accelerated to a cruising speed
of 360-380 km/h.

3.5 When the cruising speed has been reached the starting engines usually ~~work~~ are shut down, and the cruising engine works in the mode that is about 0,85 of the nominal one.

3.6 During the cruising mode:
- flight altitude is 0,5-1,0 m (up to 3 meters), - dependi on the sea state
- flaps are retracted
- the pitch is 0°-1°;
- the roll is 0.

3.7 The fuel consumption in the cruising mode is about 30 tons per one hour of flight.

3.8 When performing a turn (R = 2,5-5,0 km) the thrus of the cruising engine is increased and the altitu is increased up to 3,0-4,0 meters; the roll is 5-10°(15 and the wingship performs a coordinated turn with th flaps working in the aileron mode.

3.9 When landing the thrust of the cruising engine is changed, the flaps are extracted to +30°, the altitude of the flight is 3,0-4,0 m, the hydroskies are in landing mode position, (that is, they are fully extracted), and the pitch is slightly increased.

...ter.

3.10 ... 250 km/h

3.11 When the wingship is decelerating the flaps are retracted (so that they won't get damaged when touching the water), and during the taxiing (160-170 km/h) the blowing under the wing is switched on, (the nose engines are switched on before the landing), but during the demonstration flight, due to its brevity and due to the sea state, they weren't shut off during the flight at all.

3.12 The calculated vertical acceleration at the takeoff - landing mode is about 5-6 g units
– side acceleration (the calculated (or the regular) one is about 1,5-2,0 g units.

During the demonstration flight during takeoff and landing the pressure loads on the hull and the wing of the wingship were considerably lower than the ones built into the design.

$W_f = 3 \frac{mt}{hr} = 6600 \frac{lb}{hr}$ W: 264,000 lb [illegible] 337 $\frac{ft}{s}$

$W = 120\ mt = 264{,}000\ lb$

$V = 370 \frac{km}{hr} = 337 \frac{ft}{sec}$

$W_f = BSFC \left[\frac{lb}{sec \cdot hr}\right] \cdot V \left[\frac{km}{hr}\right] \cdot \frac{D}{L} \cdot W\ [lb]$ [illegible]

$6600 \frac{lb}{hr} = (BSFC\ \frac{D}{L}) [illegible] \cdot 337 \cdot 264{,}000$

$\frac{L}{D}$ (BSFC) $\frac{6600 \cdot 550}{337 \cdot 264{,}000}$ $\frac{lb}{hp \cdot hr}$ [illegible]

$\frac{D}{L}$ (BSFC) = .0405

$\frac{D}{L}$ (BSFC) = .0418 $\frac{lb}{hp}$

DRAFT

Russia Visit / Notes / Hooker

1.0 Mahachkala / Kaspiysk Visit and Flight Demonstration

1.1 General

The likely possibility of flying aboard the Orlyonok, taking video recordings of the cockpit as well as outside horizon references etc., and later review (and possibly retain) flight recorder data, had most of us and certainly myself in a state of happy anticipation on our arrival to the Leningrad hotel in Mahachkala, the capital of Dagistan. The small industrial town of Kaspiysk where the demonstration flight was to take place a day later is located a short distance south of the capital, and when we arrived there we were in fact the first Americans to set foot in the town since its founding in the 1950's.

We arrived at a small naval facility in Kaspiysk located directly on the shore of the Caspian sea before midday on the 28th of September 1993. Our bus pulled up alongside the Orlyonok which was parked on a concrete ramp located inside a pair of break waters which were angled acutely out to sea narrowing the entry into the sheltered waters of the small harbor. Nearly perpendicular to the ramp was a second smaller rectangular inlet in which sat a large rectangular barge and behind which on the shore rested the Lun with its six missile tubes atop the fuselage, and another Orlyonok missing its cruise engine (NK-12). This we learned had been removed and installed in the demonstration Orlyonok we were about to watch fly. Three hover craft and the Utka (Orlyonok prototype) were also in the area.

We had by this point in the journey discovered we would not be allowed to ride aboard during the demonstration, we would not be allowed to go aboard before or after the demonstration and we would not be provided any data from a flight recorder or any other source, but we would be allowed to question the crew and various engineering staff members of the Central Hydrofoil Design Bureau after the demonstration. Such discussions in fact took place later that afternoon on our return to Mahachkala. Before discovering that we would not enjoy any kind of data acquisition other than answers to mostly ad hoc questions from some of the delegation members I

had requested several times that we, as a delegation, should sit and plan a proper strategy to acquire as much technical information as possible by filming from within and outside (meaning some would stay ashore or on a boat) during the flight, and that during the flight certain maneuvers be requested. The evening before the demonstration we did spend about an hour developing such a "flight test plan" and Roger Gallington set it down on paper and submitted to the proper authorities. Though hurriedly done, and I thought rather late, it nonetheless seemed adequate and in keeping with the constant change in venue that characterized both the visit and demonstration.

Beside this hurried attempt to put together an intelligent "flight observation plan" there had been apparently a letter sent much earlier by Colonel Francis requesting similar information requesting there be observed steady state cruise, take-off and landing, simple maneuvers and in particular a turn made in free air (i.e. out of surface effect) similar to those observed in the last visit with the Striezh. Also an amphibious demonstration was requested. The demonstration we were given essentially complied with there requests except the amphibious demonstration only took place from and onto the prepared concrete ramp. Films we have seen do, however, demonstrate the Orlyonok coming in over surf onto a beach and subsequently leaving it. This same letter may also have asked for releasable previous flight data, in any event Colonel Francis reiterated the request to Dr. Boris Chubikov during our first substantive meeting that took place Monday (the day before the demonstration) afternoon/evening. Dr. Chubikov indicated he never saw the letter but had heard of it, and added that the demonstration the next day would not include free air flight since there were restrictions placed on them from the flight regulating body at TsAGI. (Flights up to 80 meters had taken place in the past and it was expected that TsAGI would soon allow an official flight ceiling of 2 kilometers). Also he indicated the only reason we could not observe a beach amphibious demonstration is that these were now only conducted at Chechen island located quite some distance to the north. Dr. Chubikov did at this initial meeting say it would be impossible for any of the delegation to ride aboard the Orlyonok, such was simply "against the law" but if we could secure permission from the navy we were welcome aboard before and after the flight. We did not apparently secure the necessary permission or it was simply denied us. To what extent there was coordination between Central Hydrofoil Design Bureau and the navy was not clear, and in fact denials may have been for reasons other than stated, and perhaps the navy and security may have been used to protect everything from

sensitive/substantive information to embarrassingly no information. But, on watching a most impressive take-off and flight of the Orlyonok Tuesday in what were reported as between 2 and 3 meter waves, there is little question on viewing the performance of the craft and crew and appreciating the engineering and construction underlying these, that good and practical data exist irrespective of our being denied any of it.

Before describing the demonstration flight in more detail and the discussions that followed, it is important to record Colonel Francis' briefing to Dr. Chubikov at the end of the Monday meeting and some recommendations that came from this exchange. Colonel Francis briefly described the progress of the WTET and ended by putting forth two candidate recommendations that would involve Russian participation: (1) some sort of cooperative design(s) study and (2) the use of a "new" Lun/Spasatel as a test bed with instrumentation brought from U.S. but tests conducted in Russia (Kaspiysk?). Col. Francis expressed the notion that if the two countries could *work together* then the United States would probably take greater notice and more progress might result. To these ideas Chubikov replied that he did not think the Lun/Spasatel test bed idea was worth while. The Lun was too specific a vehicle and could not be used in the future, but a joint design study or a parallel set of design studies to maximal sizes using releasable Russian data would be best approach. These discussions ended with Dr. Chubikov expressing their immediate concerns of survival and the pursuit of other clients and the design and manufacture of smaller craft, and Col. Francis offering the possibility of some Russian specialists coming to the United States for some unspecified time during the Phase II effort if that were to materialize.

1.2 Orlyonok Flight Demonstration - Walk Around

On exiting the bus and having been requested and cautioned not to photograph in the direction of the Lun, the delegation began walking around and examining the parked Number 26 Orlyonok and photographing it. All three engines were shut down, but the APU was running. The horizontal and vertical tail as well as the upper surface of the wing were clearly of aircraft like riveted skin construction. The hull (lower fuselage) as well as the underside of the wing were welded aluminum and in places quite thick. Later we were told that thicknesses ranged up to one centimeter. Many details are evident in the photographs and videos taken, and I will not elaborate on the

obvious ones here. For me there were few surprises since I have studied these craft for some time, and a fair amount of information is even contained in the compendium. The few details that interested me are listed next:

- airfoil zero camber under surface
- rough welding high beads, at least for this wing no underside laminar flow
- substantial incidence 4 to 6 degrees
- no aerodynamic leading edge treatment (internal anti ice thumpers), small leading edge radius
- outboard span underside leading edge flaps with external manual releases. This was a bit of a surprises and I learned later they were an Alexeeyev design feature to promote better pressure distribution during on land (amphibian) PAR departure. They in fact only marginally help, and were considered by all to be not worth the effort of installing them, however they were Alexyev's idea and no one dared suggest removing them, thus they remain there to this day.

THESE WERE IN FACT MENTIONED IN THE COMPENDIUM. I MISSED IT. SFH

- that the wing is used for buoyancy, while the videos of KM suggest that it is completely hull borne in displacement mode. (see discussion of take-off below)
- a lot of bird impacts on the leading edge of the horizontal
- overall design is of a ship that has learned to fly not "wing in surface effect airplane". The incorporation of many intelligent engineering design features, too numerous to mention, e.g. double chine at the prow, spray rail arrangements, the hydro ski, simple nozzle trunnion, external hydraulic lines where appropriate, wing hull blending,

1.3 Demonstration Flight

See and narrate videos

1.4 Demonstration Flight Debriefings (PER PILOT & SOKOLOV)

(a) Take-Off Gross Weight = 120 mTon
(b) Sea "state" = 1.5 to 2.0 m plus wind waves and chop - these conditions exceed design by 0.5 meters. (I also heard values as high as 2.7m quoted by the flight crew and others).
(c) Max Loads experienced (not at c.g.) were 5-6g and max lateral (also not at c.g.) 1.5 to 2.0 g. I was later informed that typically the vertical accelerations experienced at the center of gravity for the Lun, the Orlyonok

and the KM ranged between 0.2 to o.5. On one occasion during early tests of KM (late 1960's early 1970's)an unexpected wave encounter during manual flight caused a short duration 2.0 g peak at the KM's c.g.

(d) NE Speed 400 Km/hr (unexplained q limit)

(e) Free air stall speed 250 Km/hr

(f) For multiple obstacle avoidance radar system provides pilot a recommended course ... pilot can choose Thrust, Pitch and/or Direct Lift (Flaps). At cruise speed there is no problem detecting and clearing 100m obstacle vertically.

Speed [*knots*]	Thrust NK-12 [mTon]	Thrust NK-8s [mTon]	Delta Flap [Deg]	Delta Nozzle [Deg]	Delta Ski [% Down] **	Theta (Body Pitch) [Deg]	Alt [m]
TAKE-OFF and CRUISE							
0-28,38	15	21	0	0	20-60%	>1	0
28-38	15	21	0	+15	20-60%	>1	0
81-97	15	21	Extend -20	+15	20-60%	>1	0 (Take-Off)
108-125	15	21	20	+15	20-60%	>1	
135 +	15	21	20-Retract	0 to -5	0%	>1	
CRUISE							
195-205	12-13*	0	0	0 to -5	0%	0-1	0.5 to 1.5***
LANDING (Can land with one engine out) (Cross wind employs crab)							
195-205	Reduce	On (Low Idle)	30		100%	>1	Climb 3-4 [m]
135 Ski Contact	Varies		Retracted during decel	+15			

TAXI
86-92   Varies   21   0   +15

* L/D=10, at 10-13 mTons for NK-12 only and fuel flow between 2.5 and 3.0 mTon/hour
** Full down is 1.5 meters
***Up to 3 meters

TURNS
Turn Radius 2.5 to 5.0 Km depending, with roll up to 15 degrees, speed of 360 Km/hr height of between 3 to 4 meters and the NK-12 at 100% power lever. The turn is normally executed coordinated, flap(s) acting as ailerons (see compendium).

CLIMB
A climb from surface effect cruise at fixed power to about 30 meters will see a decrease in speed of about 15 to 20 Km/hr.

PILOT COMMENTS

SOKOLOV SUMMARY (Written)

2.0 Design Discussions with Sokolov and Diomidov
(Sokolov, Diomidov, Gera, Hooker)

3.0 Visit with Academician Logvinovich of TsAGI
(Logvinovich, Gallington, Hooker)

Wingship Investigation

Reliability and Maintainability

CONTENTS

Appendix H

o **Engine Reliability, Maintainability, Availability and Relationship to Mission Need - an Overview**

With most engine types and applications, good reliability and maintainability surface as a non-trivial requirement in order to achieve high availability. Since wingships are envisioned to have 4 to 20 engines (depending upon size and design), the RM&A aspects of propulsion on these vehicles in a difficult marine environment are expected to be of considerable interest. Some expectations using current NAVAIR in-service engine statistics are presented as highlights below, as do mission need information which is interprteted from this data.

Several main conclusions came from the review of USN engine statistics, as applied to a large WIG vehicle, and were:

1) Availability, A(o), will suffer only modestly (5%) for a 20 engined vehicle vs 8 to 10 engines, as long as the vehicle gets adequate logistic support with labor and parts. However, A(o) can be substantially reduced from the following:

- Immaturity if "new" - worth 6.7% in A(o)
- Poorly integrated into logistic system - worth 18%
- Abandoned by logistic system - worth 40%

In all instances examined where A(o) was low for that system, the biggest reason for the excessive down time was not the effort of the blue collar personnel making the repair (time down for repairs) but rather, it was down time waiting for parts, ie the logistic supply chain. It is suggested that apparent failures of the logistic system are not actually that, but are more likely the result of difficult choices to be made when parts and resources are scarce. The strongest mission needs are believed to be what are supported while those less closely linked to that are supported as best they can. Throughout the WTET effort the two seemingly strongest unique WIG missions were (1) heavy sea lift during the first few weeks of a foreign war, ie before ships could get there and (2) as a sea sitting missile carrier to help keep the areas inland from the coast soft, and ineffective for opposition reinforcement. Discussions with the Russians did not make their mission need for WIGs crystal clear and a top-down advocacy appeared to be what has kept R&D there funded rather than management's response to a ground swell of need.

2) The maintenance effort per vehicle flight hour should be proportional to the number of engines on board, as summarized below. Maintenance needs were lower for newer engine models and, inexplicably, many turboprop/turboshaft engines,including some very old designs. See the following

table for these statistics and their application to a Wingship.

Summary of NAVAIR Statistics and Wingship Expectations

Item	Best	**F110**	Worst	AVG	**WIG20** DRY	**WIG12** WET
	(-----Engine Hour Basis-----)				(Vehicle Hour Basis)	
ER/1000 H	0.2	**0.4**	2.6	1.2	**8.0**	**4.8**
EMA/1000 H	34	**36.2**	154	57.8	**724**	**434**
EMH/EMA	6.6	**6.6**	30.7	13.0	**6.6**	**4.0**
EMH/1000FH	200	**238**	1800	800	**4760**	**2856**

[ER = Engine Removals; H = Hours; EMA = Engine Maintenance Action; EMH = Engine Maintenance Labor Hours; WET means the same engine as the DRY case but with the addition of a fan duct augmentor to provide 38% more takeoff thrust, with 40% less installed engines]

Navy Engine R&M Review

The attachment in the rear shows what the R&M statistics were for all the aircraft gas turbines under NAVAIR's cog from 4/91 through 3/92. Both individual engine and "class averages" are shown. The figures of "merit" we are interested in developing here include engine removals, number of engine maintenance actions and engine maintenance hours, all per 1000 engine flight hours. The impact of reliability upon overall aircraft availability, A(o), is investigated as a separate value, with the preceding figures of merit used to support that discussion. The key feature in the immediate analysis is that values for the above figures of merit for 20 engines are 20 times the values for a single engine. For the WIG, values for one of the presently most reliable engines, the F110, will be used.

Where information was available from the Russians owing to the trips there by the WTET, these information are factored into the applicable portion of the US data discussion.

Engine Removals (ERs) - NAVAIR experienced a range of 0.2 to 2.6 ER's per 1000 engine flight hours for all aircraft types, with the class avg being 1.2. The overall best engine was the T56, which sees very little LCF type operation and has a ER of 0.2, despite the fact it was first qualified in 1956. The worst values (1.6 or higher) were for the older turbojets and turbofans. The best values were for the newer models - F110, F404 and the turboshafts and turboprops - T56, 64, 400, 700, none of which was over 0.9. All were initially qualified before 1975 and all but the T56 are used in helicopters which see substantial LCF exposure. Their

emergence as reliability leaders in these data was not anticipated. The value for the F110 (an augmented TF, qualified in the mid 1980's, installed in the F14D) was 0.4. For a 20 engined Wingship (WIG_{20}) the expectation, if the engines were as good as the F110, would be 8 removals every 1000 vehicle flight hours.

One factor in how USN engine maintenance is done in contrast to that of the Russian WIG's is worth mentioning. This is the fact that we change our engines upon cause, and not until. Each removal of an individual engine represents a halt in operations, which for a wingship might not be a small inconvenience.

When the Russians were visited in 1993, they indicated that unlike our Navy practice of engine removals only for cause, they changed all wingship engines at about a 500 hour interval. (2 Er's/1000 hours - which is higher than our average but better than our worst engine ER rate). The fact that their WIG's operations are interrupted just once for an engine change may be a practice aimed at minimizing the impact of engine removals upon A(o) and should be considered for adoption for any future US wingship operations. Unless the WIG fleet becomes large, it should also be recognized that this will cause both an activity and a budget "spike" in wingship logistic systems, particularly if only a few hundred hours of use are generated annually. It seems very probable that operational WIG personnel would judge this to be worth the irritation to the logistic system.

Engine Maintenance Actions (EMAs)/EH - The NAVAIR range is now 34 to 154 EMA's per 1000 engine flight hours for all aircraft types, with the class avg being 57.8/1000 hours. The best were the F404 (43.7) and the F110 (36.2) plus 2/3rds of the turboprops and turboshafts - T400, 700, 56, and 64 (33.9 - 47.6). The worst were the older jets and fans (70.9 to 158.7). For a WIG_{20} with F110 quality engines, the value would be 724 EMAs/1000 vehicle flight hours.

Engine Maintenance Man Hours Per Maint Action - in 1991, this ranged from 6.6 (again the F110) to 30.7 with the average being 13.0. Two thirds of the engines were within +/-3 hrs/MA of the avg. The best engines outside this range were the J85, F110 and the T700. The worst outside the range were the J79, TF30, F404 and T64. A WIG_{20} using engines as good as the F110 would take no more than 6.6 man hours for any one of 20 individual engines.

Engine Maintenance Man Hours (EMMHs)/EH - the value for NAVAIR ranged from 200 to 1800 per 1000 engine flight hours, with the class avg being 800. Slightly over half the engines were in the range of only +/- 200 from the class avg. Outside that range, the best engines were the F110 (238) plus

the T700 (300) and T56 (500). The worst were the old jets and fans plus the F404 at 1800. A WIG20 with engines as good as the F110 would absorb about 4760 EMMH per 1000 vehicle flight hours. Just for the purposes of comparison, this is roughly the equivalent of the maintenance hours that would go into the upkeep of the engines on a pair of C-2A's in 1000 hours of flight. (1.3 MH/EH for a T56-A-425 in a C-2A).

OVERALL IMPACT OF ENGINE R&M UPON VEHICLE AVAILABILITY, A(o), AND RESULTING USEFULNESS

A(o), aircraft availability owing to propulsion readiness is the % of clock or calendar time that the vehicle is in an "UP" status and is mission capable as far as the engines are concerned. This is frequently the result of all of the above plus a number of intangibles. A(o) for the above USN inventory was examined to determine whether or not availability suffered as the number of engines increased. As will be shown, A(o) did diminish as the number of engines increased but there are other factors that appear to mean as much, if not more - including engine maturity and adequacy of the logistic pipeline to meet the operational demands of the vehicle type and how it is deployed. The WIG would be such an innovation to the existing system that these factors could become very important to the success of the operational concept. The innovation is in two areas - vehicle type and it is not clear who would be the Using Service - NAVAIR, NAVSEA or another entity??

The following discusses the range of down time needed to support flight time where "other factors" as explained are apparently involved.

In logistics analysis, A(o) = (EIS - NMC)/EIS
or (1 - NMC/EIS)

where A(o) = operational availability of vehicle fleet
EIS = in service hours = number of A/C x Clock Hrs.
NMC = non mission capable hours (because of engines in the cases shown) which is usually the sum of two time values - time down waiting for parts + clock time to perform the work.

Sample Calculation: Navy data says the T56 fleet in twins and four engine A/C was used in 450.7 planes and generated 537796.5 NMC hours over a 1 year period (47.7 flight hrs/month/aircraft).

A(o) = [1 - (537796.5/450.7 x 8760)] = 0.864, which is what they show. For planners, A(o) is a very valuable number because it is a measure of how ready the equipment actually is, not how difficult it is to maintain that readiness. The obvious question then is how do various multi

and single engined aircraft in the Navy inventory stack up in terms of A(o), and why.

o **Availability, A(o) Trends** - For NAVAIR engines the A(o) values range from a low of 53.4% (S3A/TF34) to a high of 97.3%.(F4/J79) with the class avg being 88.0%.

NAVAIR shows a modest decrease in A(o) for the same basic engine as the number of engines increase. Examples follow.

. For the J52, the A(o) for both the twin A-6 and the single engined A-4 is 93.6% (47 hrs down time/mo.). This is despite the fact that they both have the same MH/EH and each generates about 28 hours vehicle flight time/mo. This suggests that when an A-6 is down for engines, it gets back to an "up" status in the same elapsed time but uses twice the labor of the A-4. Thus despite more engines, the effort and coordination of the organization appears to keep the A-6 as ready as the A-4, via 58 MH/mo for the A-6 and 24.3 MH/mo for the A-4.

. The Series III T56 on a 4 engined P3-C has an A(o) value of 86.4 vs 88.9% for the same Series T56 in the twin engined E2. This exists even though repairs on the Grumman E-2C with its extremely tight nacelle takes 0.558 MH/EH vs the 0.427 MH/EH on the accessible nacelle of the Lockheed P-3. The A(o) difference of 2.5% in favor of the E-2C literally means that the 4 engines on a P-3 usually require about 20 more down time hours each month than the two on an E-2C. Each P-3C in the example generates 92 engine maintenance MH/mo and each E-2C requires 42.6 MH/mo.

. The new Series IV T56-A-427 on the E-2C+ is a follow-on development of a nearly new from the centerline out version of the older Series III T56-A-425. It's use via substitution for the older A-425 is identical. However, it suffered from an underfunded development program and now, being in service about 3 years, has an A(o) of only 82.2%. The older 425 in the identical airframe has an A(o) of 88.9%. The 427 has still not been through OPEVAL because of it's maturity problems. (Note that on all new commercial engines, the FAA waits several years for reliability to improve before they expect it to generate a low enough unplanned shutdown rate to be permitted for use in transoceanic flights.) USN planning did not acknowledge this immaturity on the 427.

. The last T56 example is that of the T56-A-425 in the C-2A, COD aircraft. The engines and their nacelle are exactly identical with that of the E-2C. Even the airframes are as identical as Grumman can make them. The big difference is that the C-2A is the step-child of the E-2C community. No C-2A pilot in command has ever gotten much beyond where he is at present rank in the C-2A. They are now flown by female aviators, and the attitude of deck crews once they have completed their deliveries and pickups is to "get that piece of junk off my deck". All repair work is done at a land station (Sigonella, Italy for example) from bases

generally with less than boat priority on parts to handle the C-2A. Some C-2A's have flown in for Depot level rework at North Island (San Diego) with engine wiring harnesses fabricated and repaired in the field with Sears and Roebuck 12 gauge household electrical cable, because issue harnesses were not in the supply system for them. The A(o) of its E-2C counterpart is 88.9%. The A(o) of the C-2A is only 71.1%. This equates to a monthly down time of 214.3 hours on each aircraft. The man power expended monthly is about half of that, which means that even if only one man (two or more is likely) was working each plane, the down time waiting for parts is no less than half the reason for the poor A(o) on the C-2A, and is probably 75% or more of the problem.

The worst example in the grouping was the S3A/TF34 with an A(o) of only 53.4%. The S3A is the fixed wing ASW aircraft for the carrier group. This aircraft is in a non mission capable status almost six months of the year. Out of 120.3 A/C, with 240.6 engines, 40 engines or 16.6% were cannibalized to keep the others going. The overall USN cannibalization rate for the rest of their aircraft is about 1/3rd that of the TF34, ie 5.7%. The operating TF34s' generate 99398 engine hours/yr (34.4 hrs/month avg for each of the 240 engines) with a component failure rate (MTBF) of one every 29 engine hours. This MBTF is not too encouraging compared to the 60 hrs on the F110, the 65.5 hrs for the T56 or the 86.9 hrs on the F404 - but equal to that of the J52 in either the A-4 or the A-6 which are well supported and get an A(o) of 93.6%. The S3A is down most of the time therefore not because of equipment failures but rather because of the maintenance situation on the ground/deck, as the following statistics prove. The man hours for engine repair on the TF34 is 1.4 MH/EH which equates to 48 man hrs/month per engine. Even if only one man was available to do the work, the clock time for this would not exceed 6.6% of the available time. The 23.4% balance of the unavailability (46.6 - 16.6 - 6.6 = 23.4%) is down time waiting for the system to repair the engines. A likely suspect here would be unavailability of parts. One conversation with NAVAIR in January 1993 indicated that they were expecting a shipment of 50 engines to accommodate the lack of parts for repair of problems that "had finally caught up with them". Nonetheless, if the component of unavailability owing to cannibalization is added in (16.6%), this says that system shortages on the TF34 have kept it on the ground over 40% of the time. The TF34 in the S3A (same basic engine as in the USAF A-10) appears to have been abandoned by the Navy supply system.

There appears to be enough data in the above to identify an impact of the number of engines upon A(o) in both adequately and otherwise supported systems. This is shown in the figure in a log-log relationship. The figure suggests that a vehicle with 20 engines capable of an A(o) for a single or twin of about 93.6% would have an A(o) for 8

engines of about 80% and for 20, A(o) would be about 75%. In a 8760 hour year, each WIG vehicle should anticipate propulsion as a lump causing 1750 (for 8) to 2200 (for 20) clock hours of down time annually - and this is for a fully mature engine, a dependable logistic pipeline and good morale with the troops. Down time for other system components like the airframe/hull, loading gear, etc, would be in addition to this.

The few data where the engine system is not adequately supported in the field or may not yet be fully mature are also shown on the figure. Their effects are contrasted with the multi-engine effects and are as follows:

- Using 20 instead of 8 engines - worth 5% in A(o)
- Non-maturity - worth 6.7% in A(o)
- Needed but not well integrated into the pipeline; seen as a dead ended career position - worth 17.8% in A(o).
- Basically abandoned by supply - worth 40% in A(o).

One message here is that the quality and even existence of the logistics pipeline, the attitudes of the organizational units, and even the assurance from the Acquisition System manager that a newly developed engine will initially be as good or better than other more mature engines can hurt A(o) far more than equipment that breaks down periodically. The other is that when parts are in short supply, system managers in the service may have no choice but to make distinctions between which aircraft get the best support and which do not. In an environment where those sorts of difficult management choices exist, the A(o) for a 20 engined WIG vehicle could fall to about 68% for the early years of service and about 58% if the logistic pipe line suffers from priority problems. If supply abandons it, A(o) would fall to around 40%, which could put the WIG in a museum or storage and make it non-operational. Clearly, good A(o) requires that a WIG have very high Mission Need in the using service.

ATTACHMENT A

ACTUAL USN ENGINE R&M DATA - WORLDWIDE

April 1991 to March 1992

List 2

[redacted]

ENGINE COMPONENT IMPROVEMENT FEEDBACK REPORT

[redacted] ENGINE SUMMARY

APR 91 - MAR 92

PREPARED BY:
NAVAL AIR SYSTEM COMMAND
IRM APPLICATIONS BRANCH (AIR-71334)

PREPARED FOR:
NAVAL AIR SYSTEMS COMMAND (AIR-536)

GLOSSARY

A(O)	Operational Availability, calculated as the difference between the Equipment in Service (EIS) hours and Not Mission Capable (NMC) hours divided by the EIS hours, (EIS-NMC)/EIS.
A/1000 EFH -	Aborts per 1000 Engine Flight Hours, the number of Aborts divided by the quantity Engine Flight Hours divided by 1000. *
Aborts -	Number of maintenance actions with a When Discovered code of A or C. *
Aborts, % In-Flt -	Aborts, percent In Flight, the percentage of inflight Aborts (When Discovered code of C). *
Aborts, % Failure -	Aborts, percent Failure, the percentage of Aborts due to Failure.
Aircraft -	Equipment in Service (EIS) hours divided by hours in report date period, produces an average number of aircraft over a one year period.
ATC -	Action Taken Code, this code describes the action accomplished on the item identified by the WUC. *
BCM -	Beyond the Capability of Maintenence, denotes that the item is beyond the capabillty of an Intermediate Maintenance Activity (IMA) to repair. The item will be forwarded to a depot. BCM is documented by the numeric Action Taken codes "1" through "9". *
CR/1000 EFH -	Component Removals per 1000 Engine Flight Hours, the number of Maintenance Actions with an O-level Action Taken code of P,R,S, or T (minus the number of engine removals) divided by the quantity Engine Flight Hours divided by 1000. *
EFH/F (MTBF) -	Engine Flight Hour per Failure, (Mean Time Between Failure), calculated as the number of Engine Flight Hours divided by the number of Failures.

ENGINE: T56

STATISTICAL SUMMARY BY AIRCRAFT/ENGINE COMBINATION
APR 91 THRU MAR 92

REPORT DATE: 08/03/92
REPORT: JETMF400

COMMAND/ -ELEMENT--	T56-A-7 C-130F	T56-A-16 KC-130F	T56-A-16 EC-130Q	T56-A-16 KC-130R	T56-A-425 C-2A	T56-A-425 E-2C	T56-A-427 E-2C+	T56-A-10WA P-3A	T56-A-14 P-3B	T56-A-14 P-3C	T56-A-14 EP-3E
AIRCRAFT	4.7	25.4	5.4	10.0	28.3	57.2	16.4	0.7	82.6	211.9	8.1
ENGINES	18.8	101.6	21.6	40.0	56.6	114.4	32.8	2.8	330.4	847.6	32.4
SORTIES	1430.0	5849.0	549.0	2767.0	7930.0	9080.0	2791.0	138.0	11832.0	31568.0	1262.0
FLIGHT HRS	4442.0	17148.0	2357.0	7585.0	14592.0	26215.0	8099.0	451.0	33060.0	137334.0	6701.0
ENG FLT HRS	17768.0	68592.0	9428.0	30340.0	29184.0	52430.0	16198.0	1804.0	132240.0	549336.0	26804.0
>EFH/F,MTBF	57.9	84.1	48.3	139.8	31.4	43.0	40.6	24.7	68.9	70.2	73.8
>EFH/MA,MTBMA	34.4	47.1	25.2	79.4	15.7	17.2	11.1	13.5	32.9	31.5	26.2
MAINT ACTION	516.0	1455.0	374.0	382.0	1864.0	3049.0	1459.0	134.0	4018.0	17435.0	1025.0
ENG CANNIBAL	0.0	9.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	10.0	1.0
FOD MA	2.0	4.0	1.0	0.0	11.0	5.0	3.0	0.0	3.0	42.0	1.0
FOD/1000 EFH	0.1	0.1	0.1	0.0	0.4	0.1	0.2	0.0	0.0	0.1	0.0
>CR/1000 EFH	6.8	4.4	7.4	2.9	17.5	14.4	40.2	3.9	5.8	7.2	5.2
FAILURES	307.0	816.0	195.0	217.0	929.0	1219.0	399.0	73.0	1918.0	7822.0	363.0
EMT	5360.3	11281.4	3731.8	2808.5	13890.8	12940.4	15073.4	3399.4	27397.2	105340.9	5399.4
>EMT/MA,MTTR	10.4	7.8	10.0	7.4	7.5	4.2	10.3	25.4	6.8	6.0	5.3
MAN HOURS	13406.4	28679.7	8571.0	8105.3	37430.5	29248.4	42369.9	10026.4	62197.5	234686.6	13585.5
>MMH/EFH	0.8	0.4	0.9	0.3	1.3	0.6	2.6	5.6	0.5	0.4	0.5
MMH/MA	26.0	19.7	22.9	21.2	20.1	9.6	29.0	74.8	15.5	13.5	13.3
NMC HRS	9705.4	13744.4	4276.7	2835.8	72786.3	56731.8	28198.2	626.0	78300.1	255543.8	19048.4
% NMCS	36.5	33.4	52.4	63.3	30.1	46.8	9.5	40.0	57.2	26.4	28.7
% NMCM	63.5	66.6	47.6	36.7	69.9	53.2	90.5	60.0	42.8	73.6	71.3
% AWM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>NMC/EFH	0.5	0.2	0.5	0.1	2.5	1.1	1.6	0.3	0.6	0.5	0.7
ABORTS	12.0	52.0	18.0	8.0	53.0	74.0	36.0	8.0	185.0	683.0	37.0
% IN-FLT	16.7	26.9	27.8	62.5	28.3	35.1	36.1	75.0	55.7	52.6	70.3
% FAILURE	66.7	69.2	77.8	50.0	62.3	74.3	63.9	50.0	63.8	74.4	67.6
>A/1000 EFH	0.7	0.8	1.9	0.3	1.8	1.4	2.2	4.4	1.4	1.2	1.4
>FA/1000 EFH	0.5	0.5	1.5	0.1	1.1	1.0	1.4	2.2	0.9	0.9	0.9
ENG REMOVALS	4.0	27.0	4.0	4.0	17.0	7.0	5.0	1.0	41.0	104.0	10.0
>ER/1000 EFH	0.2	0.4	0.4	0.1	0.6	0.1	0.3	0.6	0.3	0.2	0.4
>FER/1000 EFH	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1
A(O)	77.5	93.9	91.1	96.8	71.1	88.9	82.2	90.9	89.6	86.4	73.6

?

ENGINE: T56

REPORT DATE: 08/03/92
REPORT: JETMF400

STATISTICAL SUMMARY BY AIRCRAFT/ENGINE COMBINATION
APR 91 THRU MAR 92

COMMAND/ -ELEMENT--	OVERALL
AIRCRAFT	450.7
ENGINES	1599.0
SORTIES	75196.0
FLIGHT HRS	257984.0
ENG FLT HRS	934124.0
>EFH/F,MTBF	65.5
>EFH/MA,MTBMA	29.5
MAINT ACTION	31711.0
ENG CANNIBAL	24.0
FOD MA	72.0
FOD/1000 EFH	0.1
>CR/1000 EFH	7.9
FAILURES	14258.0
EMT	206623.5
>EMT/MA,MTTR	6.5
MAN HOURS	488307.2
>MMH/EFH	0.5
MMH/MA	15.4
NMC HRS	537796.5
% NMCS	33.5
% NMCM	66.5
% AWM	0.0
>NMC/EFH	0.6
ABORTS	1165.0
% IN-FLT	49.2
% FAILURE	71.0
>A/1000 EFH	1.2
>FA/1000 EFH	0.9
ENG REMOVALS	224.0
>ER/1000 EFH	0.2
>FER/1000 EFH	0.1
A(0)	86.6

T56
Avg Navy A/C Has 3.62 Engines.

INE: ALL

STATISTICAL SUM , ENGINE TYPE
APR 9 U MAR 92

COMMAND/ -ELEMENT--	J85	TF34	F402	F404	F110	OVERALL
AIRCRAFT	156.9	120.3	146.6	548.0	139.0	3593.6
ENGINES	313.8	240.6	145.6	1096.0	278.0	7474.6
SORTIES	48870.0	21501.0	39507.0	181923.0	31725.0	762482.0
FLIGHT HRS	61580.0	49699.0	49754.0	223229.0	51141.0	1371988.0
ENG FLT HRS	123,160.0	99,398.0	49,754.0	446458.0	102282.0	3025224.0
>EFH/F,MTBF	29.8	26.7	18.2	86.9	60.1	46.7
>EFH/MA,MTBMA	14.1	8.4	6.3	22.9	27.6	17.3
MAINT ACTION	8738.0	11847.0	7914.0	19469.0	3705.0	174982.0
ENG CANNIBAL	51.0	40.0	10.0	107.0	5.0	650.0
FOD MA	86.0	59.0	76.0	150.0	15.0	907.0
FOD/1000 EFH	0.7	0.6	1.5	0.3	0.1	0.3
>CR/1000 EFH	4.2	16.7	32.4	7.4	8.4	7.8
FAILURES	4130.0	3725.0	2732.0	5138.0	1702.0	64781.0
EMT	44271.7	59492.8	36347.8	124953.7	10451.1	958098.1
>EMT/MA,MTTR	5.1	5.0	4.6	6.4	2.8	5.5
MAN HOURS	69878.2	138643.0	87801.7	298343.8	24376.7	2273827.2
MMH/EFH	0.8	1.4	1.8	0.7	0.2	0.8
MMH/MA	8.0	11.7	11.1	15.3	6.6	13.0
NMC HRS	363078.6	498088.4	195493.2	743431.2	90219.9	3811314.8
% NMCS	27.2	38.8	31.5	33.9	38.9	36.4
% NMCM	72.8	61.2	68.5	66.1	61.1	63.6
% AWM	0.0	0.0	0.0	0.0	0.0	0.0
>NMC/EFH	2.9	5.0	3.9	1.7	0.9	1.3
ABORTS	133.0	187.0	309.0	698.0	60.0	4776.0
% IN-FLT	31.6	21.9	46.0	53.0	31.7	43.5
% FAILURE	61.7	71.7	46.9	56.6	61.7	63.9
>A/1000 EFH	1.1	1.9	8.2	1.6	0.6	1.6
>FA/1000 EFH	0.7	1.3	2.8	0.9	0.4	1.0
ENG REMOVALS	271.0	170.0	126.0	516.0	36.0	3484.0
>ER/1000 EFH	2.2	1.7	2.5	1.2	0.4	1.2
>FER/1000 EFH	0.8	0.7	0.8	0.4	0.2	0.4
A(0)	73.7	53.4	84.9	84.6	92.6	88.0

10 - 16

.NE: ALL

STATISTICAL SUM[illegible] BY ENGINE TYPE
APR 91 ..RU MAR 92

REPORT DATE: 08. [illegible]2
REPORT: JE[illegible] [illegible]0

COMMAND/ -ELEMENT--	J52/A-4	J52/A-6	T400	T700	T56	T58	T64	T76	J79	TF30/F-14A	TF41
AIRCRAFT	342.7	374.5	131.3	237.4	450.7	457.4	165.8	42.1	15.6	255.6	9.7
ENGINES	342.7	749.0	262.6	474.8	1599.0	914.8	420.4	84.2	31.2	511.2	9.7
SORTIES	86889.0	67817.0	22716.0	47101.0	75198.0	76342.0	24120.0	6507.0	2478.0	48966.0	646.0
FLIGHT HRS	110904.0	128275.0	34643.0	102495.0	257984.0	157947.0	47065.0	12488.0	3106.0	80400.0	1258.0
ENG FLT HRS	110904.0	256550.0	69286.0	204990.0	934124.0	315894.0	119178.0	24976.0	6212.0	160800.0	1258.0
>EFH/F,MTBF	29.0	29.2	54.0	90.1	65.5	38.9	66.6	45.8	60.9	25.4	35.9
>EFH/MA,MTBMA	13.0	10.2	21.0	23.7	29.5	12.2	27.3	19.1	23.2	11.5	16.8
MAINT ACTION	8531.0	25261.0	3298.0	8649.0	31711.0	25886.0	4367.0	1311.0	268.0	13952.0	75.0
ENG CANNIBAL	87.0	113.0	1.0	15.0	24.0	115.0	13.0	2.0	3.0	64.0	0.0
FOD MA	107.0	156.0	5.0	17.0	72.0	36.0	14.0	0.0	0.0	113.0	1.0
FOD/1000 EFH	1.0	0.6	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.7	0.8
>CR/1000 EFH	5.3	7.0	11.3	7.3	7.9	5.4	4.0	7.7	13.7	8.2	11.2
FAILURES	3827.0	8786.0	1282.0	2275.0	14258.0	8128.0	1790.0	545.0	102.0	6326.0	35.0
EMT	47975.0	118297.9	18571.5	30004.0	206623.5	120422.3	28624.5	11229.7	3563.6	96770.1	498.8
>EMT/MA,MTTR	5.6	4.7	5.6	3.5	6.5	4.7	6.6	8.6	13.3	6.9	6.7
MAN HOURS	101867.7	257744.2	46043.5	61274.7	486307.2	307234.4	99543.7	21432.2	8227.9	261770.4	1337.9
>MMH/EFH	0.9	1.0	0.7	0.3	0.5	1.0	0.8	0.9	1.3	1.6	1.1
>MMH/MA	11.9	10.2	14.0	7.1	15.4	11.9	22.8	16.3	30.7	18.8	17.8
NMC HRS	191638.7	210944.6	73656.8	204424.1	537786.5	235668.2	97016.0	33346.5	3682.0	331026.7	1805.4
% NMCS	36.1	23.3	53.7	64.8	33.5	48.7	56.1	60.6	53.6	25.3	49.1
% NMCM	63.9	76.7	46.3	35.2	66.5	51.3	43.9	39.4	46.4	74.7	50.9
% AWM	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
>NMC/EFH	1.7	0.8	1.1	1.0	0.6	0.7	0.8	1.3	0.6	2.1	1.4
ABORTS	346.0	225.0	187.0	373.0	1166.0	577.0	122.0	53.0	20.0	314.0	6.0
% IN-FLT	28.0	29.8	64.2	57.6	49.2	38.8	40.2	9.4	55.0	31.2	50.0
% FAILURE	52.0	62.7	70.6	66.0	71.0	69.8	65.6	60.4	55.0	65.3	50.0
>A/1000 EFH	3.1	0.9	2.7	1.8	1.2	1.8	1.0	2.1	3.2	2.0	4.8
>FA/1000 EFH	1.6	0.5	1.9	1.2	0.9	1.3	0.7	1.3	1.8	1.3	2.4
ENG REMOVALS	335.0	562.0	14.0	78.0	224.0	652.0	102.0	39.0	17.0	341.0	1.0
>ER/1000 EFH	3.0	2.2	0.2	0.4	0.2	2.1	0.9	1.6	2.7	2.1	0.8
>FER/1000 EFH	1.0	0.4	0.0	0.2	0.1	0.8	0.4	0.7	1.3	0.5	0.0
A(O)	93.6	93.6	93.7	90.4	88.5	94.2	93.4	91.1	97.3	85.3	97.9

WASHINGTON OPERATIONS
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SRS TECHNOLOGIES

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Attn: BOB HOENIG

Phone: 310 948 8952

Originator: E. LISTER

Extension: 703-528-2470

Instructions:

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FOR GE 90 @ .4 30 FT ATTACHED.

E.

4 May 1993
052/93U-5461-70
Mod of 9/22/93

Memorandum

To: Wingship File

From: Eric Lister

Subject: **Engine Water Wash Requirements for Wingships**

References: (a) Russian Wingship Compendium, by Office of Naval Research 1992
(b) State of the Art Review, Large Turbines, Naval Air Propulsion Test Center, Trenton NJ PE-38 Report, September 1974 by Eric Lister and Robert Dobrowolski
(c) E-2C/T56-A-427 28 Day Water Wash Instruction Maintenance Cards, 1 Feb 1991
(d) F-18 Organizational Level Maintenance, Engine Water Wash, 15 April 1991

1. Purpose: This document develops suggested engine water wash and system design requirements for supporting a large wingship in the "Spasatel" class. The selected engines for this were 4 Pratt and Whitney 4000 series high by-pass commercial turbofan engines, each in the 100,000 lb thrust class. (This was the minimum engine case in the WTET supporting design study done by Northrop.) The primary objective of water washing is to avoid compressor and fan stall, (from deposits on the compressor and turbine). However, savings in fuel and parts replacement from reduced corrosion would be also likely benefits, even as they are today.

The primary objectives of the equipment and procedures identified are to show what will be needed to perform a water wash on all four engines in about one hour. It will be shown that this is in considerable contrast to current day procedures which could easily lead to reductions in wingship availability of 50%. The methods suggested also consider information which was received from the Russians during the ARPA Wingship Technical Evaluation Team (WTET) trip there in August 1993.

Owing to the likely use of warranties the government or commercial buyers would ask of the engine manufacturers of large commercial turbofans at the time, this report is based upon engine wash procedures developed and supported by the

manufacturers of current engines. Complete airplane wash techniques developed by the Navy, such as the P-3 "Wash Rack" or "Bird Bath", were not considered because it is not known if they would be viewed as being acceptable to the warranty.

2. Background: Water washing to remove sea salts and other airfoil deposits is usually done by motoring the engine with its starter at RPMs needed for starting (about 30-33%) while fluids are injected. The frequency for washing varies with the mission and appears to be strongly related to the sea salt in air content. Owing to the intent of the WTET to explore large commercial engines for this application, it seemed prudent to try to determine water washing requirements for such engines. This was further prompted by noting that reference (a) made several notations regarding efforts to keep sea water and salt water sprays out of their engines and special ducting/doors to assist in this, even when running. In the absence of detailed information on the Russian design, it was decided to use the USN and commercial information available to establish a starting point regarding water washing: (1) frequency, (2) amount and type of wash fluids required, (3) actual procedures used including pre and post wash engine prep, and (4) any special equipment used today. This information, flavored to some extent by what the Russians told the WTET later, was then used to extrapolate to the PWA 4000 series to try to make an engineering assessment of where to start to make water washing an integral part of the engine maintenance on a wingship. This is considered an initial assessment or starting point for either RDT&E or operations until more is learned about real requirements. Note that the Russians did extensive salt water ingestion testing and washing experiments at their Volga site to develop their procedures.

3. Summary of Significant Findings: It was found that large commercial turbofans are man-washed on a 1000 hour or so interval whereas wash intervals on fixed wing naval aircraft at sea can vary from 40 to 50 hours out to several hundred. In commercial aviation service, an engine wash costs about $140 in labor but saves about $2/hour in reduced fuel costs. The cruise altitude of 21 feet from the engine centerlines to the sea for the "Spasatel" class of wingships appears to be closest to that of hovering helos and seaplanes during landings and takeoffs, and is considered more severe than that of aircraft launched from a carrier deck 70 feet off the water. The above helo and seaplanes both require a rinse after each *day* of operations (wash with soap every 60 hours). The Russians said their Lun will be using an on-board engine diagnostic system to tell them when an individual signature has changed sufficiently to merit a water wash. Although their experience so far has been to do daily washes (as ours would predict), they are hopeful that they can get 100-200 hours operation between washes, depending upon (1) sea state and (2) the operator's skill in not bashing the hull on waves

and creating sprays. Keep in mind that this is their operational goal, not an in-service achievement. The needs identified below are based on USN in-service procedures for aircraft today.

The amount of fluids used on a single engine wash on the F-18/F404 and E-2/T56 is about 2 lbs of wash and rinse per lb/sec of maximum design airflow on the compressor. This is for engines with 12 to 18 stages of core compressor in series. The primary fluid used for the F404 and the T56 is clean, potable water, ie tap water. In commercial practice, some manufacturers specify minimum chloride levels and some specify demineralized water. Several wash compounds are in use - B&B 3100, TC100 and MIL-C-85704 (commercial designation not found). TC100 and MIL-C-85704 are believed to be the most environmentally acceptable. The 85704 wash fluid is used at 11% strength with water and the wash solution constitutes about 10% of the total fluids used. Below 32 deg F, the rinse and wash water must be 50-60% by volume alcohol, which is flammable either by itself or in a solution with water. In contrast to this is the Russian wingship practice which is to use only fresh water, never soap, unless they have been ingesting oily water. They said that in an emergency, they would even use raw sea water, simply to remove salty deposits, until fresh water was available. For operations far from the home port and near a hostile beach, this might become an important maintenance protocol to remember.

Using current USN aviation practices, the amount of fluids that appear to be required to wash one large turbofan with 2850 lbs/sec max fan airflow are projected to be 33 gallons of wash fluid (includes 3.6 gallons of wash compound) plus 280 gallons of water or water/alcohol for the two rinses. The Russians said they have done substantial engine testing on an outdoor stand at their Volga site to find out how little fresh water was needed and viewed the above amount as more than they would need to use. While they never said how much water was needed, they did indicate that with integral wash probes, the same as are proposed here, they felt they would obtain the quickest wash with the least amount of water. They said they were currently designing the integral wash system for their Lun.

Using current USN water to air ratios and wash/rinse cycle times, for four engines a wash with two rinses would take1242 gallons of fresh water plus 14.4 gallons of MIL-C-85704 wash compound. The fluid flow time would be 3.5 minutes - a 0.5 min wash followed by two 1.5 minute rinses. The above estimate of fluids has made a substantial allowance for the fact that a one stage fan should take much less fluid to clean it than a multistage fan or core compressor. This is also consistent with the Russian suggestion that the core is the most important item to be washed, not the fan. The

Russians indicated that in addition to generally avoiding the wash cycle, they only pressurized their starters enough to crank the engines over at about 18% - not the 30-33% we use which is "light-off" RPM. Their purpose in this was to prevent the starter from overheating and requiring a substantial wait between motoring periods. The current USN technique is to wait for the starter to cool. Their technique would simply require taking less bleed flow from the APU, which is something we might wish to consider, even for our aircraft washes, to save starters. For US wingship applications, we need to experiment with rinse time, fluid amounts and reduced speed starter operation before an operational evaluation would be feasible. If we use integtrated probes as the Russians are now trying to use, a 100 gallon rinse/engine after each flight might be a possible starting point if we wished to try less than the 300 gallons/engine suggested by our current way of washing engines. An on-board diagnostic system to define wash effectiveness by measuring conventional operating line shifts is virtually mandatory, and in fact is planned to be used by the Russians despite their current resource poor environment.

The actual time to wash, rinse and dry a single engine today is well under an hour. However, some current day practices and aircraft equipment limitations place severe restrictions on the time it takes to complete an engine wash. The more significant ones used by the USN today which would be intolerable because of their adverse effects upon wingship availability include:

o Forced use of an external starter air source instead of the available cross-bleed start systems. This is because of the inability of customer air bleed systems (ECS, SPS, CSD, etc.) to tolerate water. This forces the engines to be cranked over with an external starter cart and done one at a time in series. The Russians use an on-board APU and a manifold line to the starters for multiple simultaneous starter engagement. The cross-bleed system is not engaged.

o Engines are washed only with some difficulty and the need exists today for ground maintenance personnel to frequently alter the configuration of engine/airframe system drains, sensors and anti-icing systems before the wash and then return them to their flight configuration afterwards. A typical twin engine aircraft total wash time today can vary from three to five hours. With current day US equipment, the time to wash four engines on a wingship could easily run 9 to 10 hours. This would reduce vehicle availability due to engine maintenance on the order of 50%.

The Russians concurred wholeheartedly that the above procedures would not be adequate for wingship operations and further agreed that the one hour objective here was their objective also.

Except for the standard 33 gallon USN J1-1 "Wash Cart", and water injection probes inserted into specific airframe inlets, there appears to be little or no special equipment involved today. A wingship however could likely use an integrated approach to accomplishing a four engine water wash in under one hour. Key equipment features in such an approach should include:

- Dock facilities for generating up to 300 gallons of fresh water or water-alcohol/day per engine for wingship operation. For a 4 engine ship this amounts to 1200 gallons/day/ship.
- A single connection at the dock for vehicle wash fluids
- Separate fan and core wash systems integrated into the engine design
- Use of airframe mounted APUs to provide starter air for all engine starters simultaneously via a manifold.
- An airframe mounted "wash panel" that performs all wash system operations including any changes needed to secondary power systems or engine sub systems during a wash
- Run the starters at reduced flow and pressure to avoid overheating which produces a wash speed of about 18% vs. 33% for a start. 18% should yield a constant duty cycle for the starters with no overheating.

4. Recommendations:

o Commercial warranty information - US engine manufacturers should be asked how they would deal with water washing in their warranty of a large, high by-pass turbofan.

o Design and R&D - Until better information is available, the provisions of paragraph 3 should be considered for use in wingship integrated design. Some T&E with salt water on the PWA 4084 or a similar engine should be done to experimentally find the optimum wash fluid amount, wash procedures, and integrated probe design.

DETAILED ANALYSIS - WATER WASH

Nature of the Problem: The surge margin (SM) of fans and compressors is adversely effected by roughness of the airfoils much beyond that of a new blade. The roughness both lowers the stall line and raises the operating line. New blades will have an "RMS finish" of 8 to 10. Values of 20 to 40 RMS (which still feel reasonably smooth to the touch) can begin to produce measurable degradation in both performance (SFC, thrust, TIT) and operational suitability (SM). Values as high as 120-140 (typical of a clutch plate) have been noted on severely eroded engines in service with performance losses of 4 to 6%. The items that can produce airfoil surface roughness, even on coated parts, include:

1. Erosion (permanent)
2. Dirt and fine sand deposits (can be washed off)
3. Soot and smog deposits (can be washed off)
4. Materials in solution in ingested water (can be washed off)

In addition to the above is the fact that salt deposits also form on the turbine vanes, which close off the flow area and reduce surge margin by pushing the compressor operating line upwards. Stationary engines at inland utility sites today go through periodic washes to remove air borne solids and mineral deposits from their hot sections. Both wash and rinse cycles are used on these engines.

It is not uncommon for the logistic portion of the Navy organization to be concerned with parts replacement costs from corrosion due to the ingestion of sea salt in air (the USN J1-1 wash carts in fact are called "Corrosion Carts"). However to the operational personnel, loss of surge margin and the resulting compressor stall/AB blowout is believed to be far worse. This is because it can be a threat to safety of flight since it's sudden and unannounced onset causes a gross loss of thrust during very critical portions of operations - for example during takeoffs and landings.

This paper deals primar[illegible] with the last three and the use of fresh water and spe[illegible] remove them effectively. This [illegible]

Shifts in classic operating characteristics caused by either turbine vane area blockage or elevation of the compressor operating lines can be successfully tracked on individual engines. Degradation of the stall line itself cannot be tracked in service (except by noting unexpected stalls), but as long as the airfoils are not eroded or damaged in some way, if a wash restores the operating lines, there is an excellent chance it has also restored the stall line. Typical changes in operating line signatures that might be tracked would include: N1/N2 speed match, EGT, EPR and Wf trends. The Russians in fact stated that they were doing precisely the diagnostics mentioned above and had it enunciated via an on-board display that said "Wash Engine No. __." They indicated that EGT shifts upwards from salt ingestion between washes were as much as 50-60 deg C. on the engines in the nose which received extensive sea sprays. Compared to EGT increases seen by US engines in commercial service, it is felt that the Russian experience of 50-60 deg C. is exceptionally large - probably enough to cause warranty problems. Hopefully, a US wingship would use the same type of diagnostics, preceded by engine signature definition via T&E when first installed. The Russians said that they had never had a compressor stall on a wingship, which is a testimonial to how well they have kept up with water washing.

An additional factor that will likely make a large wingship more prone to concerns about stall margin degradation is the expectation that the engines will be "marinated" versions of the largest commercial turbofans available at the time. Typically, commercial engines do not tend to have the degree of SM that military engines do. This is due largely to the fact that they tend to see far less sand and sea salt ingestion than their military counterparts. It is not considered likely that a very large and costly commercial engine would go through further development to either drop the operating line or raise the stall line. Consequently, if SM degradation becomes a concern owing to dust or salt deposits, the most likely solution will be for the using service to perform regular engine washes. The purpose of this document is to explore what this means today and what it would entail for a very large four engine wingship.

There is good probability that any government purchase of such engines in the future would entail an engine warranty. This is felt to apply because the Navy is now using warrantees for their purchase and use of the commercial CFM56 by-pass turbofan in the E-6A as well as their purchase and use of the T56-A-427 in the E-2C. An additional reason is that engines such as the PW 4000 series are envisioned as commercial developments, not military. If a warranty is utilized for wingship engines, this would in turn depend upon the user employing maintenance practices approved by the engine manufacturer. As a result of this consideration, the

water wash analysis of this report and projections to engines as large as the PW 4000 series is based largely upon accepted present day Navy engine water wash instructions, which were supported in their development by engine manufacturers. Other present Navy techniques, such as the P-3 "Wash Rack" which is an outdoor total airplane wash facility (much like a car wash without scrubbers) were not considered because their development and use parameters fall outside the control of the engine manufacturers who would be expected to warrant their product. There are indications in this report that such methods have merit for both corrosion and engine stall margin control, but if this applies to the wingship, it will remain for the government to establish this with the engine manufacturers. In such an effort, the burden of proof would likely fall upon the buyer to establish suitability and use in an engine warranty.

Severity of the Wingship Environment: The use of the PAR system on a wingship will require it to fly close to the water - typically about 0.2 chord lengths. For the Spasatel design, this would be about 8 to 9 ft from the water to the bottom of the wing, which would place the PWA 4000 series engine centerlines about 21 ft above the water.

Figure 1 is a plot of USN data on sea salt in air concentration in PPM vs. height above the sea (reference b). Much of these data were generated in the 1960's by what in 1993 was NAWC/AD, in establishing the appropriate sea salt in air concentration to be used in creating the specification for salt water ingestion testing during engine qualification. Much of the data were generated by the same personnel using the same instrumentation (Casella cascade tester) in an effort to establish uniformity. Note a very strong increase in the amount of sea salt in air as altitude is reduced. Above 10,000 ft over land or sea the value is about 0.00004 PPM. At the height of a carrier deck (65 -70 ft) it can range from 0.02 to 0.09 PPM. At the cruise height of the Spasatel engines, 21 ft, it would range from 0.05 to 0.30 PPM. These data are interpreted to mean that the typical environment of the Spasatel will present it with about 3 times as much sea salt in air content as carrier deck operations would. It will be important later to note that the Spasatel PPM level may be the same as what the turboshaft engine in a helo during an ASW "dip" at 20 ft. would be exposed to (T700 in the SH-60). In addition, the wingships will also experience ingestion of essentially "green water" in the form of sprays and sheets from hitting waves during landings and takeoffs. The Russians acknowledged that operator skill here can effect wash interval easily by a factor of two.

For information purposes, the distribution and concentration of material held in solution in sea water

Measured Effects Of Height Over Water Upon Sea Salt In Air Content - Navy Data

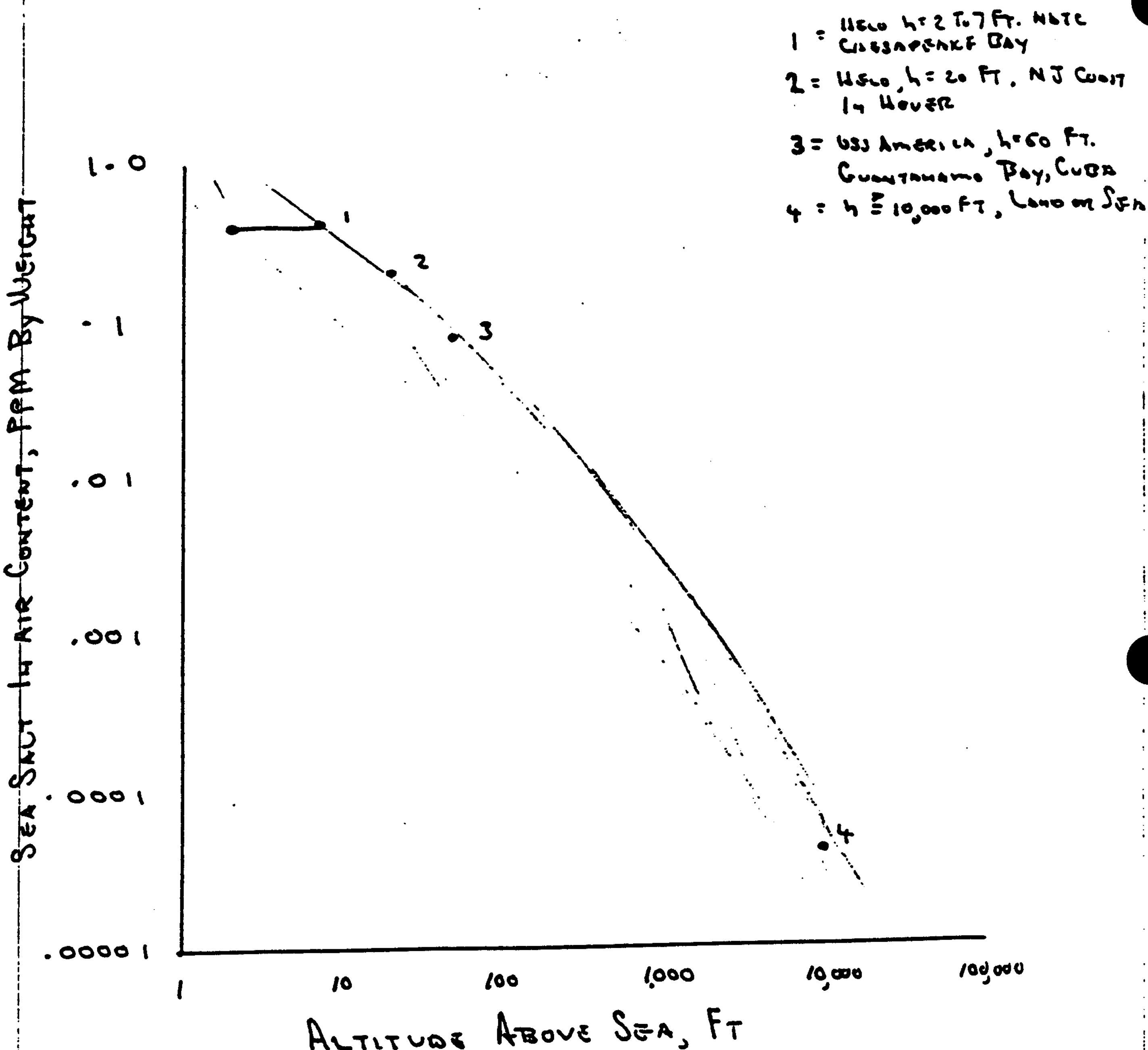

Figure - 1

Lister

varies globally. In order to have a standard to test to, in the mid 1960's, the USN engine T&E community adopted ASTMD-665 as their "standard" for what would be considered as "Spec Sea Water". This is presented in figure 2, also from reference b. It shows that synthetic sea water shall contain approximately 42 grams of dissolved minerals per liter of water. Sea water is thus 4.2% dissolved minerals by weight. NaCl comprises 58% of this. The Russians also used a specification for their salt water ingestion tests at Nishny Novgord on the Volga and their level was about 37 gms/liter.

<u>Benefits and Frequency of Water Washing</u>: "Sea salts" remain when sea water evaporates from an airfoil surface. This was a primary reason why the Russians preferred older, low pressure ratio compressor, engines for their wingship lift engines - the lower temperature evaporated less of the water in the compressor section. Since these salts are all water soluble, they would be expected to be removable with water. (Either fresh or sea water but not river water since it contains entrained mud. Inadvertent use of Delaware River water in 1957 during water ingestion tests of a J71-A-2 by the Navy resulted quickly in severe compressor stalls). When an engine is washed (procedure described later), these materials can be expected to go back into solution with fresh water (defined by USN as drinkable) and be removed from the gas path. Drainage is typically from the combustor drain and the tailpipe. Both USN aviation and land based utility/industrial gas turbines also use several available gas turbine cleaning solvents which act as the "soap" in a wash cycle which is used to precede several fresh water rinse cycles. The purpose of the solvent is to remove soot, smog and adherent fine dust even if there is no sea salt deposits. Restoration of performance based upon pre and post wash measurements is typically nearly complete except for erosion or other residual damage due to age (FOD, cracked metal, turbine vane bow, etc.). Major corrosion damage is said to also be effectively prevented.

Military engines going through their qualification testing at the manufacturers plant are generally operated with electrostatic and other types of air filtration systems, which are not necessarily too effective. These engines typically gain back 2- 4% of the 4-5% performance loss noted during the endurance testing once they are washed and rinsed.

Operational USN aircraft, particularly sea based, use water washing to avoid both progressive losses in performance and SM. Specific examples of effectiveness follow.

o T56-A-425/E-2C - During the early 1980's, the fleet was advised to wash the engines in the twin engined E-2C every 7 days when at sea and operating about 40-50 hours monthly and

Photographic examples of microstructure in the scale of corroded turbine blades are given in Figures 34 through 36 (from References 17 and 18). The scale from a IN-713C turbine vane similar to the one shown in Figure 27 was analyzed by the contractor, Lycoming, for chemical content, using an electron beam microprobe. The results of this analysis are presented in Figure 37. This analysis was the basis of the scale description by Lycoming, presented in Table I, above. The microstructure of the scale on the blade in Figure 29 (NI-100) is presented in Figure 35. The microstructure of the severely corroded IN-713C Navy aircraft blade of Figure 33 is shown in Figure 36. In Figure 36, the two inner layers and the visual appearance of the microstructure mentioned in Table I can be seen.

B. Sources of Sulfur Which Causes Sulfidation

The two principal items that go through the gas turbine powerplant which contain sulfur (S) are fuel and sea water. The maximum amount of sulfur in JP-4 and JP-5 fuels is limited by the MIL-J-5624F specification to 0.4 percent. The actual distribution of sulfur in JP-5 type fuels was given by Phillips Petroleum Company as follows (Reference 19):

TABLE II

	0.004 to 0.04 percent by weight	0.04 to 0.4 percent by weight
Foreign	12%	88%
Domestic	40%	60%

Reference 19 states that the average JP-5 fuel contains 0.1 percent sulfur (U. S. Bureau of Mines Surveys, 1957 to 1964).

The chemical content of what ASTMD-665 defines as synthetic sea water is given below:

TABLE III

SALT	FORMULA	GRAMS/LITER
Sodium Chloride	$NaCl$	24.54
Magnesium Chloride	$MgCl_2$-$6H_2O$	11.10
Sodium Sulfate	Na_2SO_4	4.09
Calcium Chloride	$CaCl_2$	1.16
Potassium Chloride	KCL	0.69
Sodium Bicarbonate	$NaHCO_3$	0.20
Potassium Bromide	KBr	0.10
Strontium Chloride	$SrCl_2$-$6H_2O$	0.04
Boric Acid	H_3BO_3	0.03
Sodium Flouride	NaF	0.003
	Total	41.953

Figure 2

every 56 days when land based. Washing aboard ship however, is a difficult task in part because of the effort to break the launch/recover/store cycle and partially because of the 4-5 hours it takes to perform the wash plus post wash engine performance checks at sea. The post wash requirement is for a high power check which cannot be done on the E-2C with the wings folded. Once the wings are unfolded, the aircraft must be on the flight deck, which tends to shut down flight deck launch and recovery operations for other aircraft owing to the 66 ft span of the E-2C. As a consequence of this plus fleet personnel not being particularly aware that salt deposits were forming which would cause compressor stalls, many E-2C's never received an engine wash for their entire tour at sea, perhaps six months and 240-300 engine hours later. A number of these had experienced what the fleet termed "bogdown", but generally only on one engine at a time. Bogdown was an uncommanded rpm loss usually accompanied by a compressor stall that occurred after a power lever transient on takeoff or landing, sometimes with both engines. A primary and contributing cause was lack of surge margin from salt/soot deposits. The cause was that the prop blade angle could not reduce as fast as fuel flow on a power reduction, RPM on the 100% constant speed prop would fall off, and the 96% rpm triggered 5th and 10th stage bleeds which would open and frequently stall the downstream stages. When water washing was enforced at 28 day intervals (every 40-50 hours) along with periodic cleaning and lubrication of the 5th and 10th stage bleed valves plus keeping the constant speed propeller blade angle and it's stops in trim, the problem largely vanished. The item that forced bogdown into becoming an action item for NAVAIR to correct was a double bogdown that occurred during a missed arrestment at night on a twin engine E-2C. The pilot recovered, made a successful go around and arrested landing and subsequently received the Air Medal.

During this same period, very similar T56 models in the land based P-3's experienced substantially fewer bogdowns, despite similar utilization rates and substantial amounts of operation at very low altitudes, even more so than the E-2C. The reason for their success is felt in some part to be due to the fact that P-3 squadrons get a daily overall anti-corrosion wash in the "wash rack" or "bird bath". This is a large set of fresh water spray bars and nozzles through which the aircraft pulls itself slowly at walking speed with the engines at high rpm but low power. Such a technique might prove worthwhile for the fans on a wingship. However, cores are designed to keep water out, which suggests that washing of the core (high spool) would require some other means than external sprays to remove salt deposits.

o F404-GE-400/F18 - On a sea tour, these engines are not normally washed until they return to port 6 months later. Navy statistics suggest that the F-18 community generates

about 30-40 flight hours per month/aircraft. During Desert Shield, the twin engined F-18's were used much more extensively than during an ordinary tour, sometimes up to 20 hours in one 24 hour period. NAS Lemore reported that some of the F-18s had experienced A/B blowout and automatic relight a second or so later immediately following launch. (This author's unconfirmed suspicion is that A/B blowout was due to a fan stall induced by inlet pressure distortion upon rotation with fans suffering from degraded SM.) After unsuccessfully trying a number of things at the organizational level to identify and correct the problem, the offending engines were given a wash and rinse while at sea.*1 Dirt, dust and sharply eroded leading edges had been felt on the F404 fan blades from the desert environment nearby. The A/B blowouts were said to never reoccur, even with the erosion, as long as the engines were regularly washed at sea.

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*1 When washing aboard a carrier is not pre-planned into the integration of operational flight and maintenance cycles, it must be appreciated by the reader that this is a difficult task to arrange. The first time it was done out of cycle in 1983 on an E-2C at sea, it took 14 hours just to get the E-2C into position to perform the wash.

o TF30-P-412/F14A - the first TF30 model was qualified in 1960. It has had a number of in-service problems with compressor and fan stalls to the extent that in 1985, PWA had conducted an R&D program to try to build a control that would let the engine operate safely while the compressor or fan was in stall. Today, it is required that this engine go through the complete wash and rinse cycle every 125 hours regardless of how it is operated or based.

o F100/F14B,D - GE has specified that this engine be washed based upon on-condition monitoring, rather than operating time.

o T700/SH-60 - this twin engined ASW helicopter is used frequently to drop a sensor from a 20 ft hover and listen for signals indicating the presence of a submarine. *The mission and water wash procedures for this vehicle should be of particular interest to designers of large wingships because of their similarity in operating height to a large wingship and likely PPM sea salt in air content of about 0.20 PPM.* NAWC/AD indicates that at sea, operators are advised to rinse the T700 engines with fresh water after returning from <u>every</u> mission and to give them a complete wash as well as rinse cycle every 60 hours of operation. It is not believed that they are rinsed after every mission, but rinsing is nonetheless a frequent occurrence with the T700. It is also noteworthy that the manufacturer recognized the need to be able to readily facilitate this maintenance requirement and built in a wash system integral with

the engine. Using it is said by the manufacturer to be as simple as plugging into the aircraft with the wash hose. This is in great contrast with the amount of pre and post wash changes that must be made by a mechanic to some other engines, as will be discussed in the next section.

o Commercial seaplane engines - small turboprops in the 800-1600 SHP range used on sea planes and amphibians *are usually required by their warrantee to perform a wash and rinse cycle once daily when conducting operations from fresh or salt water.*

o Commercial practices on larger engines - frequency can vary from every day for small engines to 1200 hours for large ones depending upon the problem addressed by the wash. For example, if hot section corrosion is a source of high scrap rates from combustion formations of NalCl and fuel sulfur forming Na_2SO_4, washes daily or up to every 250 hours are used. If the problem is compressor deposits, a wash every 750 to 1200 hours may suffice. If too long a period has elapsed between washes, the adherent particles may require the ingestion of ground walnut shells (Carbo-blast). Typical wash benefits include EGT reductions of 5 -10 ^{o}C. and fuel flow reductions of 0.5-1.0%. Operators contend that even with the time and labor it takes to prep and wash an engine every 1000 hours, the process is highly cost effective. The labor cost amounts to about 4 man hours or $0.14 an engine hour but the fuel savings alone, exclusive of part life extensions, are worth $2.00 an engine hour at $1.00/gal. From these data, if the degradation rate was linear with time, the break-even point on fuel savings alone would be 70 hours. (See paper attached.)

<u>Items that Make Washing a Difficult and Time Consuming Process:</u> The message from this section is that a successful multi-engined wingship will require an engine wash system that is very well integrated with the engine, the on-board airplane APU supplied starter air manifold system in lieu of a cross-bleed start[illegible] and [illegible] dock or tender it is being serviced by. [illegible] be able to [illegible]

flying. The A(o) would fall to 50% or so in a high demand vehicle, which would be highly unsatisfactory and would require twice as many WIGs to be purchased in order to have the desired number available. Since this is not likely, washing becomes the alternative.

o Pre and Post Wash Configurational Changes Required Today - The T56 and the F404 will be used to illustrate this.

The **T56** has no integral water wash system. When a wash is required, the wash cart hose is manually filled and attached to the engine anti-icing (A/I) system. Fluids are introduced there and exit into the gas path via A/I air discharge holes in the trailing edge of the 8 inlet guide vanes in the front frame, forward of the first stage compressor rotor. This and other actions by ground personnel are required (as defined by the E-2C 28 Day Maintenance Cards at NATC, Patuxent River MD - reference c), as follows:

. Three people are required for the operation - one to work the cart, one in the cockpit and a safety observer to coordinate the two.

Below 40 ^{o}F., when a 50/50 water-alcohol mix (which is flammable and cannot be used aboard a carrier) is being used, a fire watch and fire fighting equipment are required to be ready.

1. Remove up to four access panels from each engine.
2. Inspect compressor inlet housing, IGVs and first stage rotor for corrosion, FOD, cracks and salt deposits.
3. Disconnect and cap four lines - inlet pressure to electronic fuel control, altitude static pressure to control, CDP supply line to A/I system, and torquemeter A/I supply line.
4. Disconnect air hose to 5th and 10th stage low rpm surge relief bleedline at the speed sensitive valve. Cap off speed sense valve.
5. Connect wash cart air hose to bleed valve hose above to force valves closed and keep wash fluids inside compressor.
6. Connect wash cart fluid hose at torquemeter A/I connection.
7. Attach ground starter cart to gearbox mounted pneumatic starter. Do not use cross-bleed for cranking or starting.
8. Proceed with the wash/rinse cycles and then reverse steps 1-7 and return aircraft to normal configuration in preparation for post wash "dry out" engine runs at idle.

For the E-2C, NATC/FW personnel state that a complete wash/rinse and dry task on both engines can be conducted from the time the airplane is towed in until it is towed out in 3.5 to 4 hours with very experienced ground support. They

felt that a more likely fleet time might be 4 to 5 hours. Since the actual time for the wash through dry cycle only takes about 45 minutes per engine, this suggests that the effort for pre and post wash preparation takes about 60 to 105 minutes per engine. If these engines were on a vehicle floating on water, with more difficult access to the engines being the likely case, the prep time might be more on the order of 2 to 3 hours per engine plus wash time or 5.5 to 7.5 hours total for each pair of engines. Using these same procedures, a four engined WIG vehicle would take 11 to 15 hours for a complete wash/rinse/dry cycle. Owing to the severe negative impact this would have upon A(o), procedures such as are now used on the T56 would not be an acceptable means of meeting the wash requirement.

The **F404** in the F-18 pre and post wash procedures are simpler than on the T56, however, it does not contain an integral water wash system either. On the aircraft, a wash is preceded by the installation of an inlet duct screen and a single F-18 unique wash probe which is held in the inlet hole via a bracket and quick release pins. As with the E-2C, in freezing weather, a flammable water alcohol mix is to be used, with similar fire precautions being likely. The only other special items to be accomplished by ground personnel before or after a wash/rinse/dry cycle are as follows:

1. Service the "Oil Mist system".
2. Apply external electrical power, apparently so three cockpit switches can be used to keep wash fluids out of the ECS and A/I systems which use compressor discharge air.

3a. On A/C 161353 through 161521 an engine bleed air pressure regulation and shutoff valve must be installed for the wash.

3b. On all A/C after 161521, a special tool is used to make a 1/4 turn on the ECS water wash drain, apparently to open and then close it after the wash. The above two notes appear to be associated with ensuring that no wash fluids get into the ECS system.

4. Attach the wash cart hose to the inlet screen wash probe, attach the external ground starter cart and perform the wash.
5. After the wash, ensure that water does drain from the ECS water wash drain.
6. Post wash, reverse the above procedures.

The total time for the above for both engines is estimated at about 45 minutes. Combined with a wash/rinse/dry cycle time for each engine of 35 minutes, a complete F-18 can probably be in and out of the tow bar for a wash in about 1.9 hours maximum. The complications for a wingship floating on the water using this level of SOA would be:

1. the use of an external starter cart and again, no use of the cross-bleed system

2. getting access to an underwing ECS gravity drain

3. physically installing some form of non-airframe wash probes in a very large fan with possibly a special connection for the core through multiple borescope inspection holes around the circumference of the core.

Items 2 and 3 are likely worth about an additional 1.3 to 1.5 hours per engine in a wingship installation, making the complete process time about 4.5 - 5 clock hours per engine pair, or 9-10 hours for a complete four engined wingship. Again, the large negative impact this would have upon availability would make these procedures unsatisfactory for a large wingship if it had to be done daily during operations.

o Use of ground starter cart in lieu of an airframe APU supplying hot air to a manifold to each starter - the E-2C, the F-18 and supposedly all current US multi-engined military aircraft employ a cross-bleed starting feature which cannot be used during washes because it would get the environmental control systems wet. With this feature, once one engine is started, bleed from it can be used to self start the remaining engines without the need for creating a new hookup on the second nacelle with the ground starter cart. Aircraft with four or more engines (B-52) can simultaneously start the remaining six once the first one is started and it cross-bleed starts a second unit. For a wingship, this would be an enormously useful feature for simultaneous water washing - providing it could be used for this purpose. The Russians got around this problem simply by installing several APUs inside the fuselage and running them to a manifold which went to each starter. They said all engines can be motored over for washing at the same time on their Lun. Of the two solutions, a dry CBS or an APU/Manifiold, the later seems simplest.

The F-18 information presented its cautions against using the cross-bleed feature in conjunction with concerns about keeping water out of both the secondary power system and the ECS. Damage to the ECS from entrained water was a specific hazard mentioned.

Without the use of either (1) a fuselage APU with manifolded distribution to all starters, or (2) dry cross-bleed for simultaneous washing, each engine must be done one at a time and with an external ground cart. Thus, even with only minor mechanical chores to prep the engine for wash such as on the F404/F18, it would still take 4 to 5 hours to perform the complete wash task on a four engined wingship. If this restriction could be designed out of the system, it would reduce wingship wash time to under an hour.

Obviously, what is desired for the wingship is either a fuselage mounted APU manifolded to each starter or a combined and dry cross-bleed, secondary power and EC system which keeps water out of the later two sub-systems. The APU/manifolded system is far simpler and preferred, particularly since the APU must be there anyway for other bleed air needs when in flight. The dry CBS would require development to attain the dry feature. ***The capability for simultaneous washing and motoring of all engines is identified here as an extremely important factor in keeping wingship availability high and probably will contribute more to overall propulsion availability than all other engine maintenance requirements combined.***

The Easy Part - the Wash, Rinse and Dry Cycle:

For T56 or F404, the first step in the wash procedure is to fill up the two tanks on the J1-1 Wash Cart, one for rinse the other for the cleaning compound solution. The rinse tank holds 26 gallons of "drinkable" fresh water, from any tap. If below 40 ^{O}F, this must be a solution of approximately 50/50 water and alcohol - ethyl, methanol or isopropyl, which are all toxic. The cleaning compound solution tank holds 7 gallons. The T56 information says the fluid put in this tank is to be 4 parts water and 1 part "B&B 3100" cleaner. (B&B is a well known brand in both aviation and land based power generation gas turbines for at least the past 25 years, to the extent that USN maintenance personnel refer to the entire procedure as "B&B ing" the engine rather than washing it.) Allison indicates that owing to EPA restrictions, they currently recommend a preferred cleaner, which is titled "TC100", which was also acknowledged by the T700 source at NAWC/AD. Concentration of the TC100 was not defined. For the F404, GE recommends the solvent tank be filled with 3.1 quarts of "MIL-C-85704 Turbine Engine Gas Path Cleaning Compound" and 24.9 quarts of drinkable fresh water which makes an 11% solution compared to the 20% for B&B 3100.

The second step is to allow the engine to cool statically for at least 45 minutes from shutdown or until the indicated turbine temperature is under 70 ^{O}C (T56) or 160 ^{O}C (F404). The assumed reason for this is to keep the wash water from flashing into steam when it contacts the hot section parts. (It should be noted that when an engine is shutdown in flight and allowed to windmill or if it is motored over on the ground, it cools relatively quickly and can get to within 25 ^{O}C of ambient in a few minutes, certainly less than 10.) Then prep the engine and airframe as previously defined and hook up the starter cart air hose to the engine starter. Next, the wash is done as follows:

For the T-56

1. Wash cycle - using the ground starter air cart, engage the starter for 60 seconds and no longer (starter overtemp limit). RPM should be about 33%. Begin flowing cleaning compound solution into the engine at the rate of 3 GPM as soon as the propeller begins to turn over. (The reduction gearbox does not contain a clutch.) Shut down the starter at 60 seconds, using a stop watch. Allow starter to cool and solution to soak for 10 minutes.
2. Rinse cycles - manually switch the wash cart valve from wash to rinse and reengage the starter for 60 seconds while flowing rinse water at 3 GPM into the engine. Shut down the starter at 60 seconds, and allow starter to cool and the rinse to soak for 10 minutes. Repeat this one more time for a total of two rinse cycles. Allow starter to cool for no less than 10 minutes.
3. Dry cycle - remove the caps from the disconnected engine sensor lines for Pt2 and ps7. Reconnect the A/I line to the CDP transmitter. Start engine and run at idle for 10 minutes. Then turn on A/I system for 1 minute. Shut down engine and reconnect engine sensor lines and CDP line to its transmitter.
4. Performance check - replace nacelle access panels, restart the engine and do performance checks.

Total elapsed crank and run time = 45 minutes
Total fluids used = 3 gal wash solution + 6 gal fresh water = 9 gal
Engine Airflow at 100% RPM = 33 Lbs/sec
Wash fluid/max airflow ratio = 24 Lb/33 PPS = 0.73 Lb wash/PPS max Wa
Rinse fluid/max airflow ratio = 48Lb/33 PPS = 1.5 Lb rinse/PPS max Wa.
Total fluids/max airflow ratio = 2.2 Lb/PPS max Wa

For the F404

1. Wash cycle - motor the engine with the starter at 29-33% N2 and spray cleaning compound solution for 29-31 seconds (vice 60 sec on T56) once rotor reaches 29-33% rpm (same % as on T56). The flow rate is unspecified, but other information suggests the rate is about 6 GPM, allowing 3 gallons of fluid to be used. Shut down starter and let everything cool and soak for 5 minutes (vice 10 on T56).

2. Rinse cycles - motor the engine with the starter, flowing rinse water into the engine for 1.5 minutes (vice 1 min on T56) once it attains 29-33% N2. Continue to motor starter for 1 minute after water is turned off. (vice 0 on T56). (Test cell operating instructions indicate the starter is shut down and allowed to cool for 5 minutes before proceeding.) Repeat the rinse by motoring over for 1.5

minutes while spraying water, and continue to motor over dry for 1 additional minute. Do the rinse and motor dry cycle a third time or until all the fresh water in the rinse tank is used up. The use of 26 gallons of rinse water in 3 rinse cycles of 1.5 minutes each suggests that the flow rate is about 6 GPM.

3. Dry cycle - after returning the engine to its normal configuration, it is started with the ground starter cart and run at stabilized idle for 1 minute. The ECS switch is then set to "AUTO", the A/I system is turned to "ON" and the engine is run at idle for 5 more minutes.

Total elapsed crank and run time = 34 minutes.
Total fluids used = 3 gal wash solution + 26 gal rinse water = 29 gal
Airflow at 100% N2 = 140 Lbs/sec, with 0.1 BPR through 3 stage fan
Wash fluid/max airflow ratio = 24 Lb/140 PPS = 0.17 lb wash/PPS max Wa
Rinse fluid/max airflow ratio = 232 Lb/140PPS = 1.7 lb rinse/PPS max Wa.
Total fluids/max airflow ratio = 1.9 Lbs/PPS max Wa (vice 2.2 on T56).

Suggested Wash Frequency and Fluid Quantities Required:

The following is based upon the preceding information and what is felt to be the likely salt environment for a "Spasatel" type vehicle with four PWA 4000 series, 8:1 by pass ratio turbofans in the 100,000 lb thrust class. A single stage fan discharging into the fan duct is anticipated. Very key in defining the requirements are the observations that (1) the T56 and F404 appear to use similar amounts of total wash and rinse fluids for their airflow sizes - roughly 2 lbs total fluids/PPS of max engine airflow and (2) the PWA 4000 series of engines has a multi staged core but only a single stage for the very large fan. This prompts the assumption that compared to the three stage fan of the F404, the PWA 4000 fan will require 1/3rd the amount of specific fluids/PPS max airflow for a wash or a rinse that either the F404 or T56 does today, ie 2/3 Lbs Fluids Max Wa and not 2 Lbs Fluids/PPS Max Wa.

[The thought of using a single fluid injection point in front of the fan for both fan and core is rejected. This is because most core flowpath entry designs are laid out with inward bends to discourage the entry of water. This is a requirement to avoid severe and unrecoverable core RPM loss during low power descents in rainfall (apparent rain induced flameouts), which has been a very serious operational deficiency with 2 known commercial turbofans and at least one military turbojet. It has been a contributing factor in at

least one commercial crash - DC-9, SA 242 in April 1976, New Hope GA. Thus an integral wash system, one for the fan and one for the core is desired.]

The frequency and amount of fluids below are suggested as a starting point for in-service water washing and would be what an RDT&E effort would be expected to try, evaluate and modify in order to end up with a workable operational procedure:

1) Engine wash frequency: Use an engine diagnostic system to track and flag on shifts in characteristic operating lines. In the absence of this diagnostic, rinse after daily operations as much as is practicable. Do a complete wash plus rinse only every 60 hours of operations, or when the diagnostic system shows an incomplete return of operating lines following a wash.

2) Approximate fluid requirements: Sized for a max airflow at 100% of 2850 PPS, 356 PPS of which go through core.

o Single stage front fan - 1/3rd of 3 stage F404 specific flow requirement or (2850 PPS x 2 lb/PPS)/3 = 1900 lbs total fluids, which is made up of 190 lbs wash fluid plus 1710 lbs total rinse water.

o Discharge into core stream just aft of front fan stage - 356 x 2 or 712 lbs of fluids, which is made up of 71 lbs of wash fluids plus 641 lbs of total rinse water.

A complete wash and rinse for one engine would require 190 + 71 = 261 lbs of wash fluids (33 gallons) and 1710 + 712 = 2422 lbs of rinse water (303 gallons). The 33 gallons of wash fluids contains 11% or 3.6 gallons of "MIL-C-85704 Turbine Engine Gas Patch Cleaning Compound" and 28 gallons of fresh water. The total fresh water requirement for the wash and rinse is 313 gal. Below 40 ^{o}F, the water requirement will be about half of this since 50% or 153 gallons must be ethyl, isopropyl or methanol alcohol.

One complete wash and rinse of four engines requires:

o MIL-C-85704 Cleaning Compound = 14.4 gal or 621 gal. water plus 621 gal alcohol if below 40 ^{o}F.

<u>Wash System Constraints and System Design Highlights for a Multi-Engined Wingship</u>

The preceding discussion has illustrated two major points that become major constraints for a multi-engined wingship that system design will likely have to accommodate. The first is that the time to wash four or more engines per vehicle on a frequent basis can become a major detractor from vehicle availability if it is done the way it is presently accomplished today. Unless some relatively simple design requirements are accepted, operators could conceivably spend as much time washing engines as flying them. The second is

that substantial amounts of wash fluids will be required that will have to be replenished on a frequent basis. The second item poses solvable problems in three areas - (1) the frequent acquisition of large quantities of fresh, drinkable water, (Note that in an emergency the Russians were prepared to use sea water to remove engine internal salt deposits.) (2) dealing with the fire hazard and logistics of supplying enough alcohol for a 50% solution with both wash and rinse fluids and, (3) dealing with any environmental requirements that the discharge fluids containing both cleaning solvent and alcohol may present. The following identifies major system features that are needed:

o Desired system highlights:

1) **The capability is required to perform the entire wash from the wingship flight deck and to begin the procedure within a few minutes of coming into the dock or wig tender.** This will enable the wash to begin while the main operation is loading or unloading and the time does not count against engine unavailability.

. **A two hose system from the dock containing wash fluid in one line and rinse fluid in the other** in lieu of today's manually operated "Wash Cart". These hoses will attach quickly into the wingship by the first crew member off the ship. The required dock flow rate to wash several engines simultaneously will be 63 GPM/engine for the wash line and 100 GPM/engine for the rinse line. For each day of wingship operations, the dock or tender will need both the storage, daily acquisition and possibly some waste storage capability for 3.6 gallons of engine cleaning compound, and 313 gallons of fresh drinkable water with half this in alcohol in cold weather per engine on a wingship. Environmental compliance for training in US waters will likely require a collection system and storage for used engine water/alcohol/soap mixtures. See DoD Ins 5000.1.

. **A three way electrically powered valve at the dock controlled from a vehicle "Wash Panel" on the flight deck is needed to effect wash, rinse or drain as desired.** The drain will require a dock "catch tank" to drain the airframe system of flammable water/alcohol fluids

. **A single "fluids header" line on the wingship** that delivers either wash or rinse fluids to each engine as commanded at the three way valve.

. **Separate fan and core valving at each engine** to admit fluids.

. Internal and **permanently installed fan and core wash nozzles or probes.**

. **Switching on the vehicle "Wash Panel" to permit the operation of appropriate airframe system drains, closing or opening of engine sensor lines, A/I lines, etc.** so the wash can proceed without the need for physically sending a mechanic into the nacelles to make changes as is done today.

2) **An on-board APU/manifold system that will allow all engines to motor over simultaneously** at 18% RPM for periods of up to 20 minutes, continuos duty without overheating.

3) If a dry cross bleed start system is elected in lieu of the above APU, then a **means from the "Wash Panel" is required to keep wash fluids out of all secondary power systems serviced by engine bleed. This includes** the environmental control system, secondary power systems, constant speed drives and any other customer bleed item. This is needed to be able to use the cross bleed system for motoring the engines instead of using an external air source as is done today during a wash cycle.

If the above can be built into the wingship dock and airframe/engine systems, it is very probable that the combined wash/rinse/dry cycle for all engines can be done in well under 60 minutes, and possibly as few as 30. This allows for a 20.5 minute wash/rinse, followed by a 10 min idle run to ensure dryness. **If this can be done by wingship personnel while the vehicle is loading or unloading, the detraction from vehicle availability may be nil.**

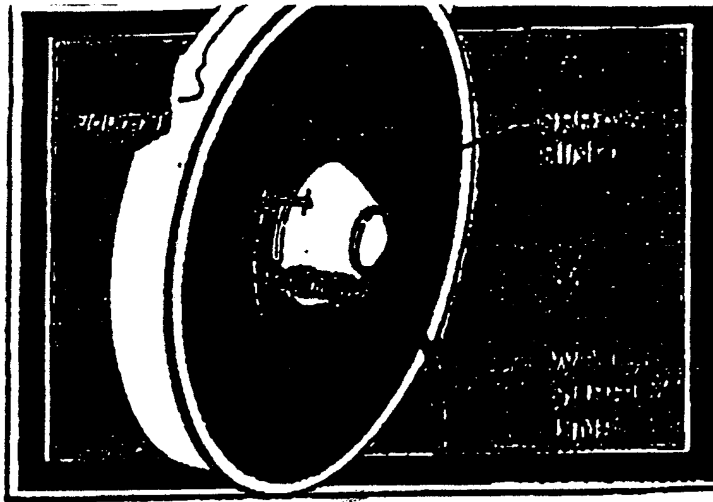
For definition purposes, an <u>engine</u> wash/rinse/dry cycle would be as follows:

. 10 min - motor engines at 18% to cool off prior to fluid injection
. 0.5 min - wash
. 5.0 min - soak, starter off
. 1.5 min - rinse
. 1.0 min - motor dry
. 1.5 min - rinse
. 1.0 min - motor dry
. 10 min - start and idle run to ensure dryness

. 30.5 min - total time for full wash (every 60 hr.)
. 25.0 min - total time for rinse only (daily operations)

WATER WASH PRACTICES INFORMATION

- Commercial
- T56/E-2C^{+}
- F404/F-18



Water wash spray ring is attached to inlet guide vanes of a turbofan engine. Note that ring is positioned toward inlet guide vane roots to maximize water flow into core gas path.

Clean Inside and Out

Engine gas path water washing could help you keep them on the wing longer and burn less fuel

By J. K. SUTER
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Commercial Products Division, United Technologies
Pratt & Whitney Group

The escalation of aircraft fuel and maintenance resource costs in the past few years has made the search for ways to reduce those costs increasingly important to aircraft operators. Many operators have found that periodic jet engine gas path cleaning, using a water or detergent ingestion procedure, is a cost-effective means of maintaining engine performance margins and maximizing on-wing time.

Because of the importance of this maintenance procedure throughout the industry, we will attempt, herein, to describe some of the background, experience, and current procedures pertinent to water and detergent washing.

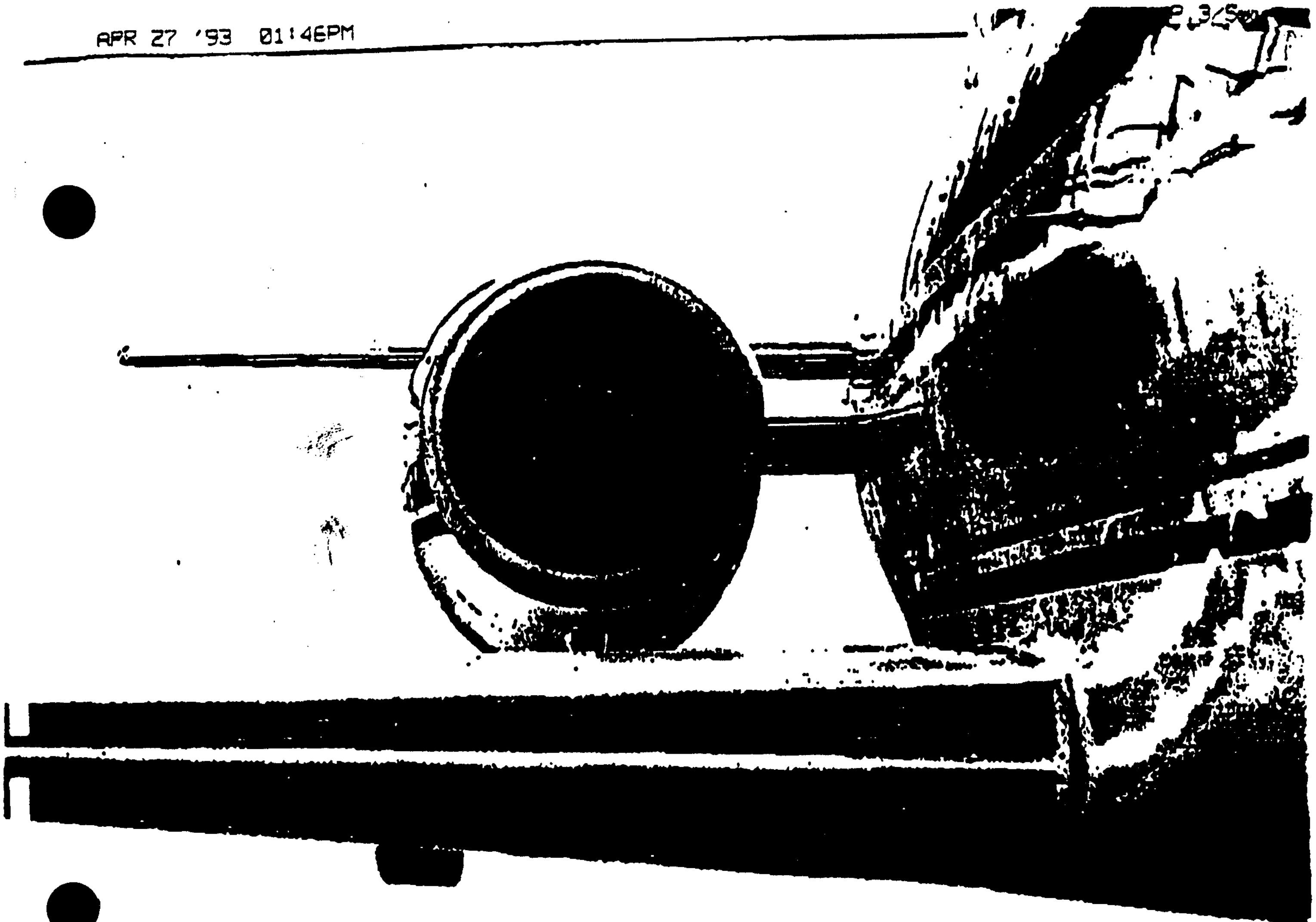
Turbine engine gas path cleaning, through ingestion of a cleaning medium, has been performed for many years to help counteract losses in compressor airfoil efficiency. Compressor blades and vanes are subject, over a period of operating time, to the accumulation of contaminants such as dust, dirt, salt, hydrocarbon residues, and corrosion products. These accumulations can cause increased engine exhaust gas temperature (EGT), increased fuel flow, and an increased tendency for engine surge or compressor stall.

Early in the history of jet engines, it was found that periodic removal of these contaminant accumulations, by ingestion of a cleaning medium, could be an effective means of reducing EGT and fuel flow, and restoring engine surge margin. The initial cleaning media used often consisted of fine cellulose-based abrasive particulates such as ground apricot pits, pecan shells or walnut shells.

One prominent engine manufacturer today specifies the use of finely ground coke as a gas path cleaning medium. With the advent of increasingly sophisticated turbine cooling schemes, and labyrinth-type main bearing seals, most manufacturers now recommend the use of water or water/detergent gas path cleaning to avoid accumulation of cleaning medium particles in critical cooling air passages and in the oil system.

Some operators report that gas path washing has been extremely effective in reducing their turbine parts scrappage rate due to sulfidation. But more on this later.

Gas path washing can be employed either on installed engines or on engines in the test cell. The procedure usually involves spraying water, or a water/detergent solution, into the compressor inlet at a prescribed flow rate for a prescribed period of time, while motoring the engine with the starter. A general discussion of procedures is



provided later in the article.

Procedures and benefits vary

Water wash procedures and utilization schedules vary among operators, based on their own experience. Some operators only use the procedure when engines exhibit ECT-limited operation or compressor surge. Other operators employ the procedure on a regular basis for installed engines, as a preventive maintenance measure, to retard the buildup of compressor contamination and maintain operating margins.

As a result, there is a wide variation in benefits reported by users. A survey of commercial airline experience shows that the following results and benefits are representative:

- ECT reductions following washing typically vary from five to 10 centigrade degrees (nine to 18 Fahrenheit degrees) relative to the pre-washed condition.
- Fuel flow reductions typically vary from 0.5 percent to 1.0 percent.
- Water wash appears to be most effective in maintaining ECT and fuel flow levels if a program of periodic washing is implemented following compressor refurbishment to retard the buildup of contaminants on gas path components. Intervals typically vary from 750 to 1,200 hours.
- Repeated or multiple water applications are generally recommended during wash of an individual engine. Each application is allowed to "soak" and loosen contaminants for a specified period, and subsequent applications then flush away the contamination.
- Engines which have operated for several thousand hours since first entering service, or since refurbishment without washing, may have a contamination buildup which is resistant to water wash alone. Detergent washes are sometimes effective in these cases, but they can require special flushing procedures or other limitations on usage as specified in the airframe or engine manufacturer's documents.
- Water or detergent solutions heated to 150° to 170°C (302° to 338°F) have been found to be more effective cleaners than those at ambient temperatures.
- Operators who experience high scrappage rates for turbine parts because of sulfidation have reported substantial reductions in scrap rates when a more frequent water wash schedule is employed. Water wash intervals, varying from daily for small engines to 250 hours for larger engines, have been reported as useful in flushing away contaminants which accelerate the hot corrosion process.

Perhaps an example would best illustrate the potential savings (see Table 1). If we look at a twin JT8D engine installation, and assume some typically reported costs and

Clean Inside and Out...

water wash benefits, it's easy to see why many operators regard water washing as being extremely cost-effective.

The example in Table 1 does not consider potential savings in turbine parts scrappage associated with water wash EGT reduction or sulfidation prevention. These added benefits further enhance the attractiveness of water washing as a simple, cost-effective maintenance procedure.

Procedures require evaluation

Water and detergent wash procedures require careful evaluation to ensure that engine (and airframe, if installed) materials and systems are not adversely affected as a result of the procedure. Following are some considerations.

Detergents should be evaluated and approved by the engine manufacturers for compatibility with the materials and coatings in the engine. Typical analysis, prior to approval, involves determination of the presence of elements which can form harmful acids or alkalies, hot corrosion characteristics, and titanium stress corrosion characteristics. A similar approval should be obtained from the nacelle or airframe manufacturer, if the procedure is to be used on installed engines.

Water must be clean. Potable water is acceptable in most procedures. However, some specify minimum chloride levels and some specify demineralized water usage.

Each engine must be evaluated to determine specific systems which must be isolated or protected from the cleaning medium. Specific attention should be given to systems utilizing engine air bleed, such as control systems sensors, service air bleed, and accessory heating/cooling ductwork.

Water or detergent wash requirements, resulting from these evaluations, are specified in the engine or airframe manufacturer's maintenance manual wash procedures.

Table 1

JT8D WATER WASH COST EFFECTIVENESS

Assumptions:

- Typical JT8D twin engine installation
- Labor cost = $35.00/manhour
- Fuel cost = $1.00/gallon
- One hour mission
- 4 manhours per water wash

Labor Cost:

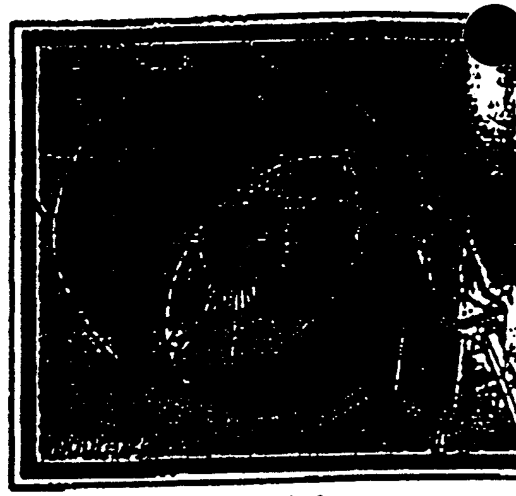
- 4 manhours x $35/manhour = $140 cost per wash
- $140 ÷ 1000 engine hours between washes = $0.14/engine hour

Fuel Savings:

- Average fuel consumption rate = 500 gal/hour
- 500 gal/hour x $1.00/gal = $500/hour fuel cost
- Typical water wash fuel flow reduction = 0.8 percent
- Assume average fuel flow reduction = 0.8/2 = 0.4 percent
- Then, fuel savings = 0.004 x $500 = $2.00/engine hour

Or,

- $0.14/engine hour in labor cost yields $2.00/engine hour in fuel savings.



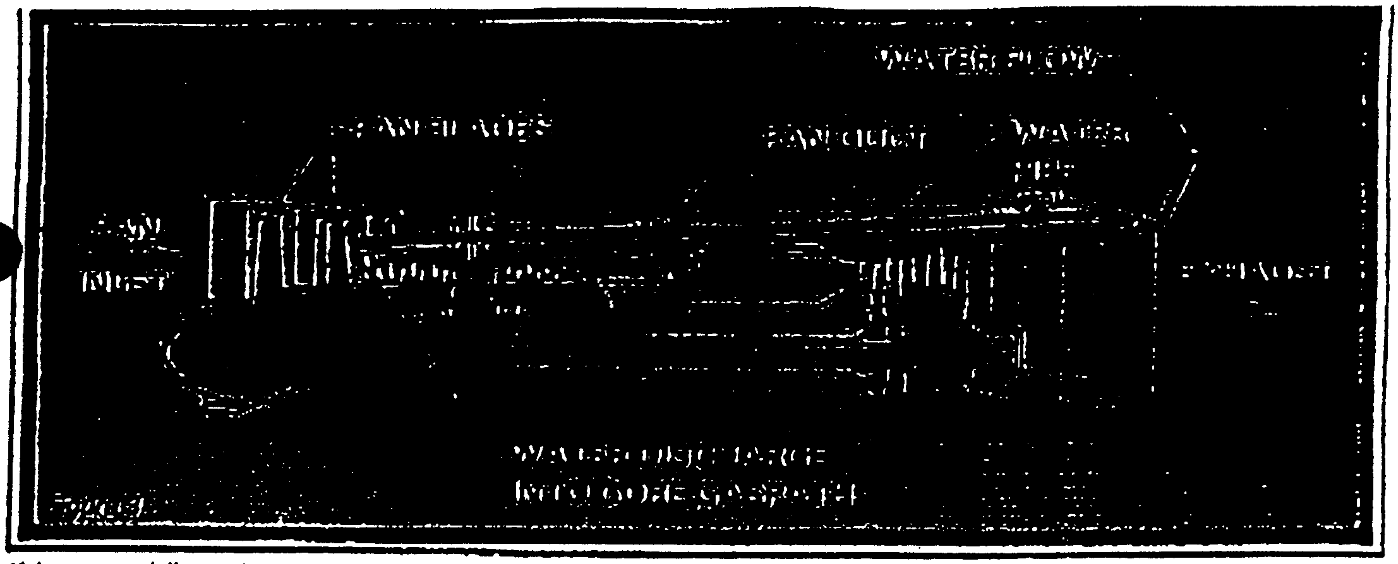
When water washing a turbofan engine using a hand-held spray nozzle, direct water stream at fan blade roots.

Although it's important to observe the specific water or detergent wash procedures specified in the engine or airframe manufacturer's maintenance manuals, some operators, after giving consideration to these recommendations, go on to develop their own version of a procedure, based on their own needs and "what works best for them." While manufacturers' and operators' procedures vary to some extent, most seem to follow a sequence like the following.

Preparation

The engine is given a general preparation for washing, first, by disconnecting pneumatic instrumentation lines, cooling ducts, and accessory component sense lines and either capping them off or connecting an air supply to them to flow air back into the engine. Service air bleeds are blanked off or closed, and the ignition system is disconnected to ensure it will not be activated during the wash procedure. Some manufacturers specify removal of instrumentation probes.

Water flow equipment is then



Using a specially configured water injection pipe is a method employed by some operators to clean core gas path.

assembled as specified in the procedure being followed. The spray device can consist of a simple nozzle, although some test cell applications utilize multiple nozzles or spray rings.

Some engines with labyrinth-type main bearing seals require oil drainage and subsequent pressurization of the breather system to prevent a detergent cleaning solution from contaminating the engine oil.

Application

The engine is usually motored with the starter, and the cleaning solution is sprayed into the compressor inlet for the prescribed amount of time, and at the recommended flow rate. In turbofan engine applications, the spray is generally directed at the fan blade roots to permit as much solution as possible to enter the engine core section. Starter operating limitations must be observed while motoring the engine for an extended period of time.

Most procedures specify spray application followed by engine rundown and a soak period for several minutes to loosen the contaminants. Then the process is repeated one or more times. Detergent wash procedures usually require a final rinse application, using plain water, to flush away the detergent.

Some engine procedures permit cleaning to be accomplished with the engine running at idle.

Because of the tendency for turbofan engines to centrifuge the cleaning solution into the fan discharge duct, and miss the core gas path, some operators have developed a method for direct discharge of cleaning solution into the core behind the fan rotor. A typical method involves the use of a cleaning solution injection pipe, which is inserted into the fan duct from the rear of the engine, until the forward end of the pipe is positioned behind the fan blades, just outboard of the entrance to the low pressure compressor core gas path. The pipe is configured with a hook or bend at the forward end which directs cleaning solution rearward, directly into the core gas path.

Some operators who have a severe turbine blade hot corrosion (sulfidation) problem utilize a procedure wherein the ignitor plugs are removed and water is injected, with specially designed probes, into the combustion chamber through the ignitor ports. Because this procedure only injects the water at two circumferential locations, it does not provide effective coverage in flushing contaminants from static turbine parts.

Restoration for service

If the oil was drained in preparation for detergent wash, the oil tank should be refilled. Most procedures then specify that engine pneumatic sense lines, cooling lines, and instrumentation be reconnected, ignition circuits reactivated, and the engine run for five to ten minutes at idle, or slightly above, to dry out the gas path and prevent corrosion or freezing because of entrapped water. During this run, most procedures specify that anti-icing air and service air bleed valves be activated open and closed to ensure that any trapped water is purged.

A detailed study of engine wash procedures, experience, and data inevitably leads you to several conclusions.

Although not all aircraft operators claim success with these procedures, many of them do. Lack of success may have been due to attempting the procedure on engines which were too badly contaminated or corroded to permit effective water or detergent wash. Still, if you are not presently using water or detergent wash, chances are that adoption of one of the approved procedures for your engine will prove to be beneficial and cost-effective.

Engine wash procedures are not only effective in cleaning the gas path for performance restoration; they also can be employed, in some engines, to remove hot section contaminants which accelerate sulfidation and resultant part scrappage.

Again be sure to observe the engine manufacturer's published procedures for water or detergent washing. In addition, if you plan to wash engines while installed on the aircraft, be sure you conform to the appropriate airframe or nacelle manufacturer's recommendations.

ORGANIZATIONAL MAINTENANCE

LINE MAINTENANCE PROCEDURES

ENGINE - WATER WASH

Reference Material

Corrosion Control Cart	NAVAIR 19-20D-1
Environmental Control Systems	A1-F18AC-410-300
Engine Bleed Air Pressure Regulation and Shutoff Valve	WP005 00
Line Maintenance Access Doors	A1-F18AC-LMM-010

WARNING

Cleaning compound will cause serious injury if not handled correctly. Wear rubber gloves, rubber apron and protective face shield. If material contacts the skin or eyes, flush the area immediately with water and report to medical facility.

Methanol is flammable, do not use near open flames or very hot surfaces. If swallowed it may be fatal or cause blindness. It cannot be made nonpoisonous. Vapors are harmful. Avoid prolonged or repeated breathing of vapors. Do not use when ambient temperature is above 40°F, unless adequate ventilation is provided according to local codes. Solution of 40% methanol and 60% water is flammable and should be treated as a flammable mixture.

CAUTION

Engine must be allowed to cool for 45 minutes and T_5C must be below 160°C before doing this procedure.

2. WASH PROCEDURE.

a. Position corrosion control cart in front of wing area approximately 10 feet from intake.

b. Connect cleaning compound hose from corrosion control cart to quick disconnect on water wash adapter (figure 1).

CAUTION

To prevent FOD, area around intake must be free of foreign objects and all equipment must be secure before motoring engine.

c. Make sure area around intake is free of foreign objects and all equipment is secure before motoring engine.

CAUTION

To ensure engine is not accidentally started during motoring procedure, be sure throttles are locked in OFF position.

d. To ensure engine is not accidentally started during motoring procedure hold both throttles in the OFF position and move throttle friction lock forward to apply full friction.

e. Apply external electrical power (WP004 00).

f. Motor engine 29 to 33% N_2 rpm (WP022 00). Spray cleaning compound into engine at 60 to 65 psi hose pressure for 29 to 31 seconds after engine reaches 29 to 33% N_2 rpm.

g. Shut down engine (WP022 00) and allow cleaner solution to soak in engine for approximately 5 minutes.

h. Disconnect cleaning compound mixture hose from quick disconnect on water wash adapter.

i. Connect fresh water hose from corrosion control cart to quick disconnect on water wash adapter.

j. Motor engine 29 to 33% N_2 rpm (WP022 00). Spray fresh water into engine at 60 to 65 psig hose pressure for 1 minute 29 to 31 seconds after engine reaches 29 to 33% N_2 RPM.

k. Shut fresh water valve off and continue motoring engine for 1 minute.

l. Repeat steps j and k, two more times or until fresh water in corrosion cart has been used (26 gallons).

m. Shut down engine (WP022 00).

3. WASH COMPLETION.

a. Disconnect fresh water hose from water wash adapter.

b. Remove upper and lower quick release pins securing water wash screen.

c. Remove water wash screen.

d. Loosen water wash adapter intake mounting clamp by pushing in and turning hand knob either direction one quarter turn.

e. Remove quick release pins securing water wash adapter to intake and remove adapter.

f. On 161353 THRU 161521, install engine bleed air pressure regulation and shutoff valve (A1-F18AC-410-300, WP005 00).

g. On 161522 AND UP, push tool 74D290110-1001 against spring force rotate one quarter turn and remove (figure 2).

CAUTION

To prevent any water from getting into ECS system, on ECS panel assembly set ECS MODE switch to OFF/RAM, CABIN PRESS switch to NORM and BLEED AIR to NORM before starting engine.

h. On ECS panel assembly set ECS MODE switch to OFF/RAM, CABIN PRESS switch to NORM and BLEED AIR to NORM.

CAUTION

To prevent water from entering Secondary Power System,do not crossbleed start engines. Use APU or ground cart.

If water does not drain from automatic drain valve, bleed air components may be damaged during engine operation.

i. Observe water draining from engine bleed air duct automatic drain valve and allow it to stop draining.

j. Start engine (WP022 00) and stabilize at ground IDLE for 1 minute. Do not crossbleed start engines. Use APU or ground cart.

k. After 1 minute at ground IDLE on ECS panel assembly, set ECS MODE switch to AUTO.

l. Set ANTI ICE ENG switch to ON.

m. Continue to run engine for a minimum of 5 minutes at ground IDLE to remove excess water.

n. Set ANTI ICE ENG switch to OFF.

o. Shut down engine (WP022 00).

4. ILLUSTRATED PARTS BREAKDOWN.

5. This illustrated parts breakdown has data required for identifying and ordering parts. The manual introduction has more information on IPB data.

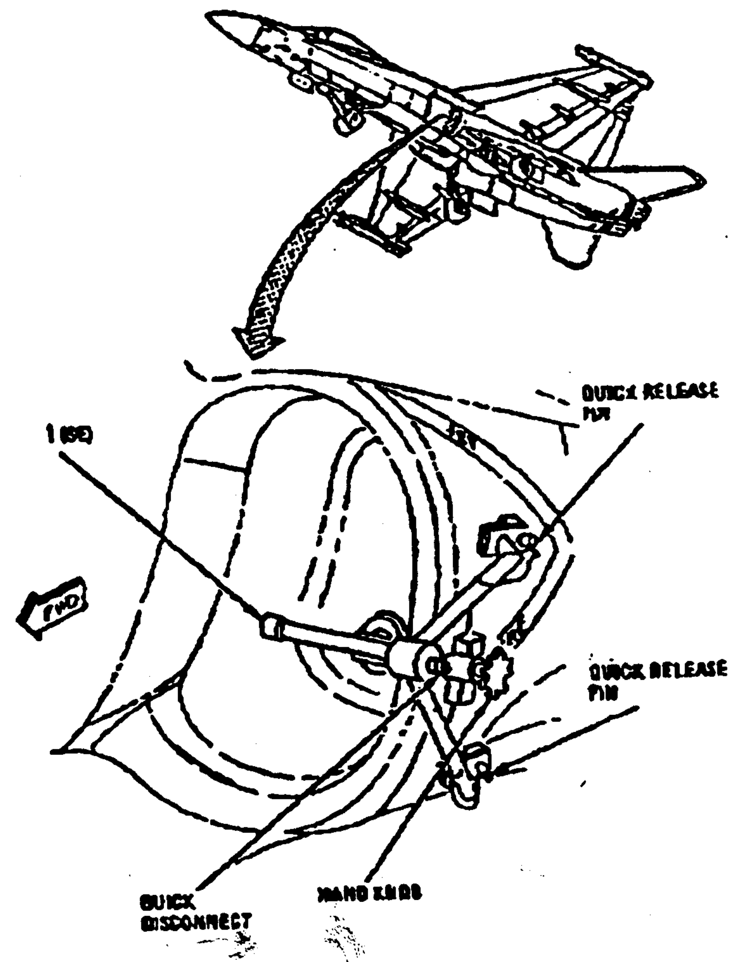


Figure 1. Water Wash Adapter (Sheet 1)

INDEX NO.	PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	UNITS PER ASSY	USE ON CODE	SM&R CODE
		WATER WASH ADAPTER			
1	21C8070001	. ADAPTER, WATERWASH (07482) .... (SUPPORT EQUIPMENT)	1		PAOZZ

Figure 1. Water Wash Adapter (Sheet 2)

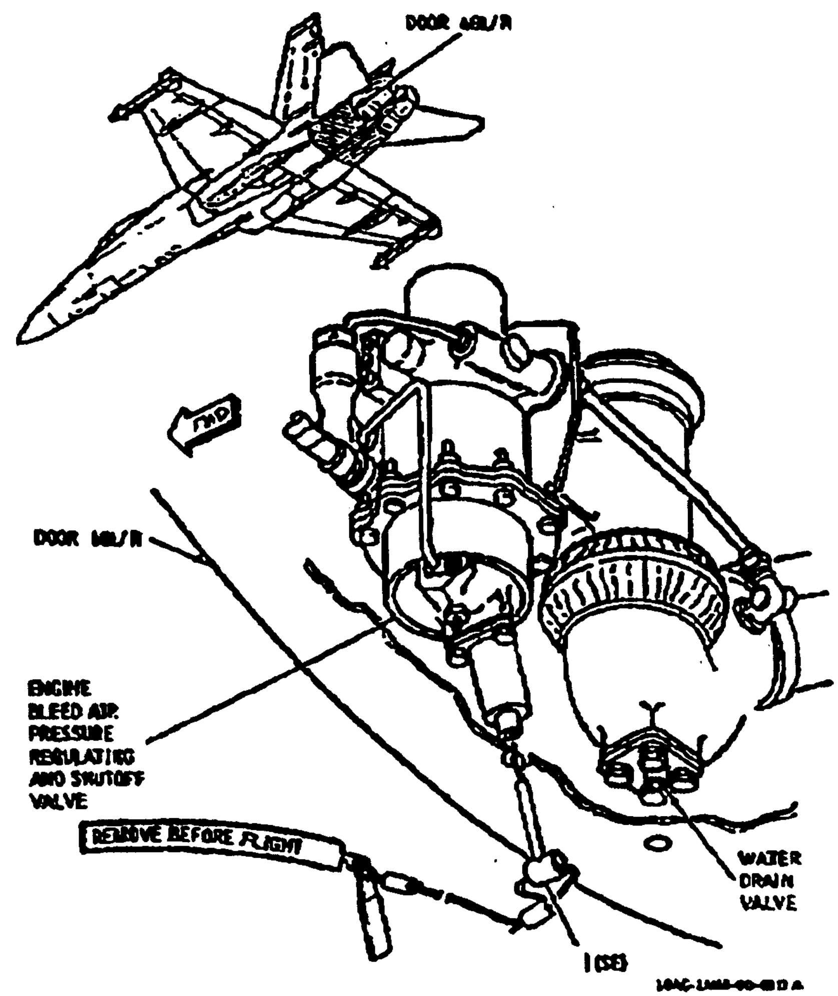


Figure 2. ECS Water Wash Drain - 161522 AND UP (Sheet 1)

INDEX NO.	PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	UNITS PER ASSY	USE ON CODE	SM&R CODE
		ECS WATER WASH DRAIN - 161522 .... AND UP			
1	74D290110-1001	. LOCK, PRESSURE REGULATING - .... ENVIR. CONTROL SYS, ENG WTR WASH (76301) (SUPPORT EQUIPMENT)	1		PAOZZ

Figure 2. ECS Water Wash Drain - 161522 AND UP (Sheet 2)

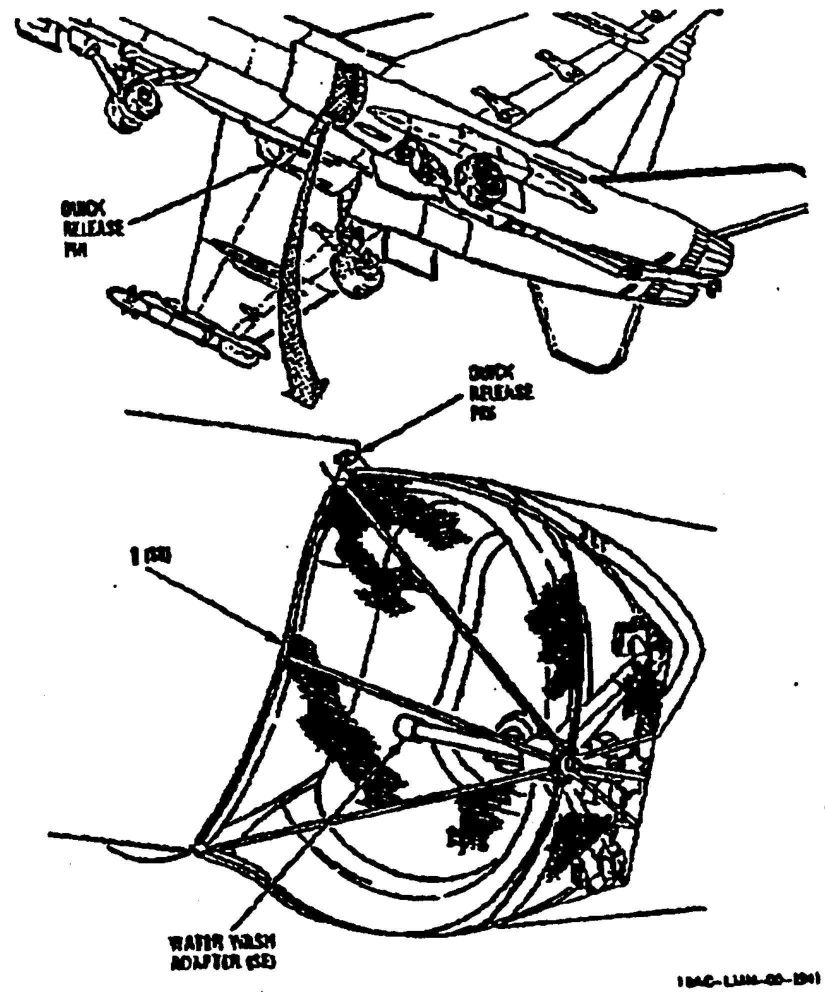


Figure 3. Waterwash Screen (Sheet 1)

INDEX NO.	PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	UNITS PER ASSY	USE ON CODE	SM&R CODE
		. WATERWASH SCREEN			
1	21C8079G01	. SCREEN, WATERWASH (07482) .... (SUPPORT EQUIPMENT)	1		PAOZZ

Figure 3. Waterwash Screen (Sheet 2)

INTERMEDIATE MAINTENANCE

ENGINE WATER-WASH

Part Nos. 6046T10G01
6084T00G01

This WP supersedes WP 015 00, dated 1 September 1989

Reference Material

Navy Occupational Safety and Health Program Manual	OPNAVINST 5100.23B
Intermediate Maintenance Manual	A1-F404A-MMI-200 and -210
Preparation for Test	WP 016 00 (Vol. 1)
Operating Limits and Test Procedures F404-GE-400 Engine	WP 017 00 (Vol. 1)
Operating Limits and Test Procedures F404-GE-402 Engine	SWP 017 01 (Vol. 1)

Alphabetical Index

Record of Applicable Technical Directives

None

Support Equipment

Part No.	Nomenclature
21C8071G01	Water-wash Set, Engine Test Cell (Superseded by 21C8071G02)
21C8071G02	Water-wash Set, Engine Test Cell (Supersedes 21C8071G01)
21C8501G01	Nozzle, Inlet
21C8505G01	Oil Mist System
65A102J1	Cart, Corrosion Control

Materials List (Consumables)

Specification or Part Number	Nomenclature
MIL-C-85704	Compound, Turbine Engine Gas Path Cleaning
O-M-232	Methanol (Methyl Alcohol)
MS20995N32	Wire, Safety

1. **INTRODUCTION.**

2. This work package (WP) contains detailed instructions necessary to water-wash the engine while installed in the test cell (WP 016 00).

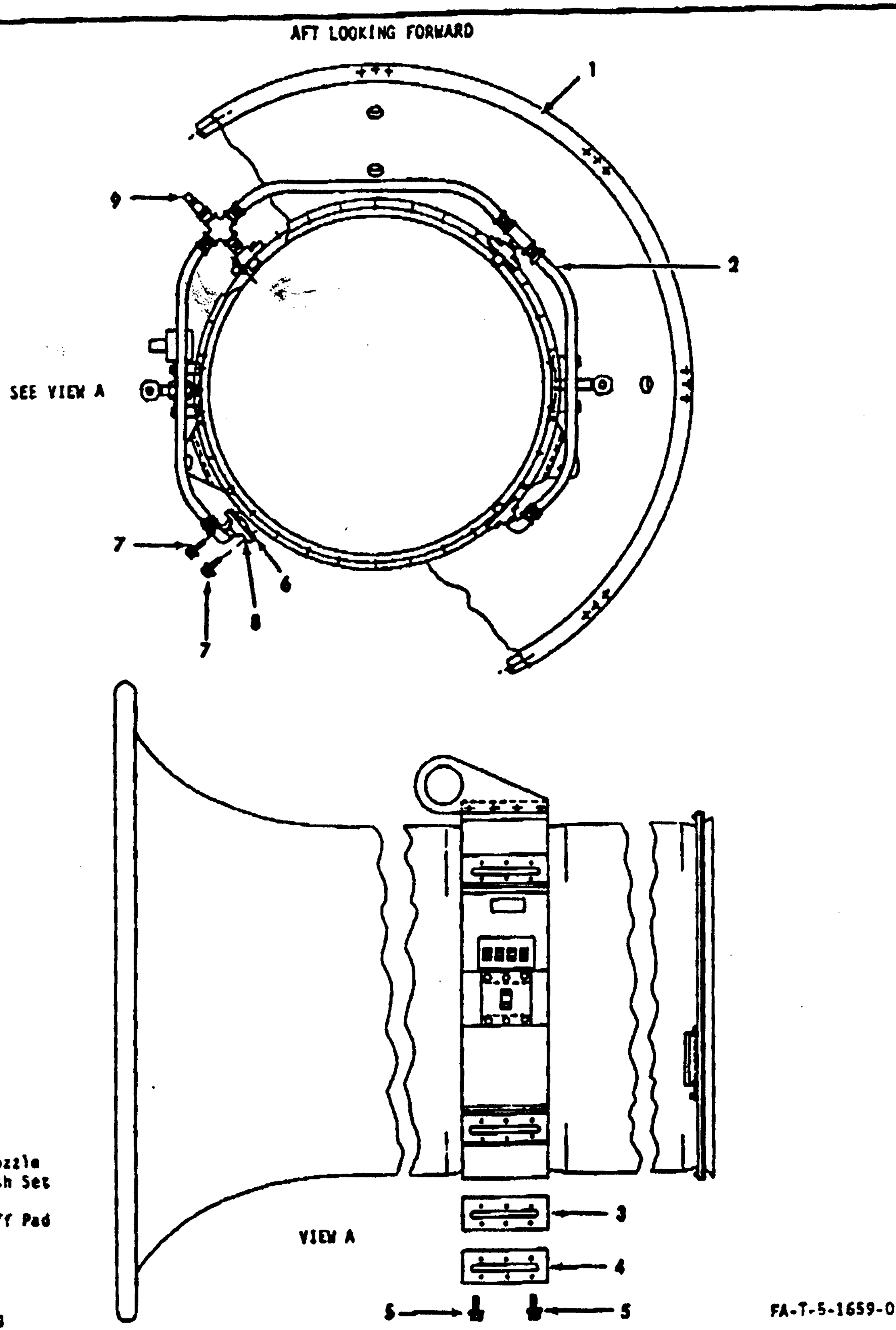
3. **INSTALLATION OF WATER-WASH SET 21C8071.**

WARNING

Removing Safety Wire

Wear goggles when removing safety wire.

a. Remove safety wire, bolts (5, figure 1), blankoff pads (4) and gaskets (3) from 1:30, 4:30, 7:30, and 10:30 o'clock positions of inlet nozzle (1) 21C8501.



1. Inlet Nozzle
2. Waterwash Set
3. Gasket
4. Blank-off Pad
5. Bolt
6. Gasket
7. Bolt
8. Plate
9. Coupling

FA-T-5-1659-0

b. Position engine test cell water-wash set (2) 21C8071 so that coupling (9) is located at 10:30 o'clock location (aft looking forward). Be sure that arrows on plates (8) point toward engine.

c. Assemble gasket (6) and plates (8) to inlet nozzle. Secure plates with bolts (7). Torque bolts to 100-120 lb in.

d. Safety wire bolts by the double-strand method, using 0.032-inch safety wire.

CAUTION

- Do not water-wash engine if ambient air temperature is below −15°F (−25°C). Ice damage will result.
- Engine shall be allowed to cool for 45 minutes minimum before spraying water into compressor. T5 shall be 320°F (160°C) or below.
- Anti-icing valve shall be closed during entire water-wash procedure.

e. Do not water-wash engine if ambient temperature is below −15°F (−25°C). Allow engine to cool for 45 minutes. T5 shall be 320°F (160°C) or below. Be sure anti-icing valve is closed. Check switch position and light indication. Anti-icing valve is closed when energized.

f. If ambient temperature is above 40°F (4°C), go to step g. If ambient temperature is 40°F (4°C) to −15°F (−25°C), do the following:

Methanol, O-M-232 **83**

(1) Fill water-rinse tank of corrosion control cart 65A102J1 with a solution of 10.4 gallons of methanol and 15.6 gallons of fresh water. = 26 gal.

(2) Pour solution of 10 quarts of methanol and 15 quarts of fresh water into solution tank of corrosion cart.

(3) Go to step i.

g. Fill water-rinse tank of corrosion control cart 65A102J1 with fresh water. (24gal)

h. Pour 24.9 quarts of fresh water into solution tank of anti-corrosion cart.

Turbine Engine Gas Path Cleaning Compound (Full Strength), MIL-C-85704 **17**

i. Add 3.1 quarts of turbine engine gas path cleaning compound to solution tank.

j. Connect quick-disconnect hose that is on solution tank of corrosion control cart to coupling (9).

4. WATER-WASH USING WATER-WASH SET 21C8071.

CAUTION

- Do not water-wash engine if ambient air temperature is below −15°F (−25°C). Ice damage will result.
- Engine shall be allowed to cool for 45 minutes minimum before spraying water into compressor. T5 shall be 320°F (160°C) or below.
- Anti-icing valve shall be closed during entire water-wash procedure.

a. Do not water-wash engine if ambient temperature is below −15°F (−25°C).

b. Allow engine to cool for 45 minutes. T5 shall be 320°F (160°C) or below. Be sure anti-icing valve is closed. Check switch position and light indication. Anti-icing valve is closed when energized.

WARNING

Oil Mist System

- Before servicing oil reservoir on oil mist system, be sure air supply is shut off at source.
- Eyes can be damaged by contact with oil propelled by compressed air. Inhalation of oil vapor can damage lungs.
- If there is any prolonged contact with skin, wash area with soap and water. If solution contacts eyes, flush eyes with water immediately. Remove saturated clothing.
- When handling liquid or working around oil mist, wear rubber gloves, goggles, and approved respiratory protection in accordance with

c. Check oil level in reservoir of oil mist 21C8505 through sight gage. If oil level is low, shut off air supply to oil mist system and service reservoir in accordance with manufacturer's instructions.

d. Turn on oil mist system 21C8505.

NOTE

Higher than normal temperatures at starter shaft bearing housing may indicate that oil mist system 21C8505 is out of oil or air supply is shut off.

e. Rotate engine to about 24% N2. If starter shaft bearing temperature exceeds 200°F (93°C), turn off starter.

f. Adjust pressure regulator on corrosion control cart to 60-65 psig.

g. Turn cleaning solution valve on, spraying solution into engine for 30 seconds.

h. Turn off cleaning solution.

i. Turn off starter. Wait 5 minutes for cleaning solution to soak into engine.

j. Disconnect supply hose from coupling (9). Connect quick-disconnect hose that is on water-rinse tank on corrosion cart to coupling (9).

k. Rotate engine to about 24% N2.

l. Turn water-rinse valve on, spraying rinse into engine for 2 minutes.

m. Turn off water-rinse. Continue to rotate engine for one more minute.

n. Turn off starter and wait five minutes.

o. Repeat steps l through n two more times, for a total of three times.

p. Turn off starter. Decrease pressure regulator to zero and disconnect rinse hose from coupling (9).

q. Start engine (WP 017 00 or SWP 017 01). Operate engine at GROUND IDLE for 5 minutes.

r. Operate anti-icing valve (WP 017 00 or SWP 017 01). Observe PS3. When PS3 drops, turn off anti-icing valve.

s. Make normal shutdown (WP 017 00 or SWP 017 01).

t. Turn off oil mist system 21C8505.

5. REMOVAL OF WATER-WASH SET 21C8071.

WARNING

Removing Safety Wire

Wear goggles when removing safety wire.

NOTE

Water-wash set may remain installed on inlet nozzle, unless special testing requirements call for use of pads.

a. Remove safety wire, bolts (7, figure 1), water-wash set (2), and gaskets (6) from inlet nozzle (1) 21C8501.

b. Assemble gaskets (3) and blankoff pads (4) to inlet nozzle (1). Secure pads with six bolts (5). Torque bolts to 100-120 lb in.

c. Safety wire bolts (5) by the double-strand method, using 0.032-inch safety wire.

CARD	NAVAIR 01-000-6 DATE 01FEB91	NA(E2AAA-6-3	CHANGE NUMBER 1	LOCA: T5.-A-427 SPECIAL 28-DAY	ELEC PWR OFF / HYD PWR N/A
WORK AREA	WORK UNIT CODE	C R S N	TIME 3.3	RTG. AD NO. 03	MOS. NO.	ENGINE COMPRESSOR WASH	COND AIR OFF

TS6-A-427

SPECIAL TOOLS/SUPPORT EQUIPMENT REQUIRED

AN 806-3K	PLUG
AN 929-4K	CAP(2)
AN 929-10K	CAP
GTC-85	COMPRESSOR, PNEUMATIC STARTING UNIT
65A102-J1-1	CART, CORROSION CONTROL

CONSUMMABLE MATERIALS REQUIRED

B&B 3100	CLEANER
-	FRESH WATER
TT-1-735 OR 0-E760	ISOPROPYL ALCOHOL

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-76) S/N 0102-LF-604-7915

SUPERSEDES NAVAIR FORM 4730/3 WHICH IS OBSOLETE

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To Eric Luster	From Bernickel
Co.	Co.
Dept.	Phone #
Fax #	Fax #

CARD | NAVAIR 01-000-6 | DATE 01FEB91 | NA01-E2AAA-6-3 | NUMBER 1

1. TO CLEAN ENGINE COMPRESSOR, PROCEED AS FOLLOWS:
   A. PERFORM SAFETY CHECKS BEFORE MAINTENANCE (NAVAIR01-E2AAA-2-1, WP040-00).
   B. INSURE THAT EXTERNAL ELECTRICAL POWER IS DISCONNECTED FROM AIRCRAFT.

CAUTION

IF ENGINE HAS BEEN RUNNING, ALLOW TO COOL FOR A MINIMUM OF 45 MINUTES OR UNTIL TMT READS 70° OR LESS.

2. PRECLEANING. WARNING

B&B 3100 CLEANER/WATER SOLUTION IS NOT TOXIC BUT FUMES MAY CAUSE IRRITATION. PROTECTION: FORCED VENTILATION, SPLASHPROOF GOGGLES, RUBBER GLOVES, AND APRON. KEEP B&B 3100 CLEANER/SOLUTION OFF OF SKIN, EYES, AND CLOTHES

NAVAIR 4790/3 (REV 7-76) BACK

CARD	NAVAIR 01-000-4 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01	LOCAL T56-A-427 SPECIAL 28-DAY	ELEC PWR OFF HYD PWR N/A
WORK AREA	WORK UNIT CODE	TIME 3.3	RTG. AD NO. 03	MOS. NO.	COND AIR OFF

WARNING

CLOSE OFF APPROPRIATE AIR BLEED DUCTS TO COCKPIT/CABIN TO PREVENT ENTRANCE OF CLEANING SOLUTION OR FUMES DURING WASHING AND DRYING CYCLES.

ENSURE THAT ENGINE IS RINSED AND DRIED FOR THE PERIODS SPECIFIED SO THAT CLEANING SOLUTION IS NOT TRAPPED IN PASSAGES, CREVICES, ETC., IN ENGINE.

CAUTION

DO NOT CLEAN THE COMPRESSOR WHEN AMBIENT TEMPURATURE IS BELOW -17°C (0° F).

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-78) S/N 0102-LF-004-7915

SUPERSEDES NAVAIR FORM 4730/3 WHICH IS OBSOLETE.

CARD	NAVAIR 01-000-4 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01

A. IF AMBIENT TEMPERATURE IS -17°C (0°F) to 4°C (40° F) PREPARE CLEANING SOLUTION AS FOLLOWS:

B. PREPARE A SOLUTION OF 50 PERCENT (BY VOLUME) ALCOHOL AND 50 PERCENT (BY VOLUME) FRESH WATER.

WARNING

EHTYL ALCOHOL, O-E-760 OR ISPROPYL ALCOHOL, TT-I-735, ARE TOXIC AND FLAMMABLE. PROTECTION: CHEMICAL SPLASH-PROOF GOGGLES AND VENTILATION; KEEP CONTAINER CLOSED; KEEP SPARKS, FLAMES, AND HEAT AWAY. KEEP ALCOHOL OFF SKIN, EYES AND CLOTHES; DO NOT BREATHE VAPORS. WEAR GLOVES.

WATER/ALCOHOL SHALL NOT BE USED FOR SHIPBOARD T-56 ENGINE COMPRESSOR WASHING.

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91				CHANGE NUMBER 01	LOCAL T56-A-427	ELEC PWR ON
WORK AREA	WORK UNIT CODE	CRSN	TIME 3.3	RTG. AD NO. 03	MOS. NO.		HYD PWR N/A COND

NOTE

WHEN USING CLEANING SOLUTION, AIR PRESSURE REGULATOR SHALL BE SET FOR PRESSURE REQUIRED TO OBTAIN FLOW RATE OF 3.0 GALLONS PER MINUTE (APPROXIMATELY 4 TO 6 PSIG). WHEN USING WATER RINSE, AIR PRESSURE REGULATOR SHALL BE SET FOR 4 TO 6 PSIG.

4. TO WASH ENGINE, PROCEED AS FOLLOWS:

A. CONNECT EXTERNAL ELECTRICAL POWER TO AIRCRAFT (NAVAIR 01-E2AAA-2-1, WP027-00).

B. CONNECT PNEUMATIC STARTING UNIT TO GROUND START CONNECTIONS IN RIGHT MAIN WHEEL WELL FOR RIGHT ENGINE OR LEFT MAIN WHEEL WELL FOR LEFT ENGINE.

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-76) S/N 0102-LF-604-7916 SUPERSEDES NAVAIR FORM 4730/3 WHICH IS OBSOLETE

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01

WARNING

CORROSION CONTROL CART AND OPERATOR MUST BE IN FULL VIEW OF PERSONNEL OPERATING ENGINE CONTROLS. PROPELLOR MUST BE IN START ANGLE POSITION.

CONDITION LEVER MUST BE IN GRD STOP POSITION DURING ENGINE MOTORING TO PREVENT ENGINE LIGHT OFF.

C. SET CONDITION LEVER TO GRD STOP.

NOTE

USE STOP WATCH TO MONITOR ENGINE TO BE MOTORED FOR 60 SECOND WASH CYCLE.

D. POSITION ENGINE START SWITCH ON ENGINE CONTROL PANEL TO L OR R TO START MOTORING APPLICABLE ENGINE. APPLY STARTING [illegible]

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91		CHANGE NUMBER 01	LOCAL T56-A-427 SPECIAL 28-DAY	ELEC PWR ON / HYD PWR N/A
WORK AREA	WORK UNIT CODE	C R S N	TIME 3.3	RTG. AD NO. 03	MOS. NO.		COND AIR ON

E. ON 65A102-J1-1 CART TURN ON AIR SOURCE TO SUPPLY 60 PSIG TO 5TH AND 10TH STAGE AIR BLEED HOSE ASSEMBLY.

F. OPEN QUICK ACTING SOLUTION VALVE ON CORROSION CONTROL CART TO ALLOW A WASH MIXTURE TO PASS THROUGH ENGINE AS ENGINE BEGINS TO ROTATE.

NOTE

SPRAY UNIT AIR PRESSURE SHOULD NOT DROP BELOW 25 PSI DURING WASH CYCLE.

G. TERMINATE ENGINE WASH AND MOTORING BY SECURING STARTING AIR AFTER 60 SECONDS; ALLOW STARTER TO COOL AND SOLUTION TO SOAK FOR A MINIMUM OF 10 MINUTES. CLOSE VALVE ON UNIT TO STOP WASH MIXTURE.

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-78) S/N 0102-LF-604-7915

SUPERSEDES NAVAIR FORM 4730/3 WHICH IS OBSOLETE.

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01

NOTE

WHEN USING 65A102-J1-1 CART, REMOVE SOLUTION SUPPLY HOSE AND CONNECT WATER SUPPLY HOSE TO THREE-WAY FITTING BEFORE STARTING DOUBLE RINSE CYCLE.

H. REPEAT STEPS A THROUGH G WITHOUT B&B 3100 CLEANER TO PERFORM WASH RINSE CYCLE. ALLOW ONLY FRESH WATER TO FLOW THROUGH ENGINE BY OPENING QUICK ACTING WATER VALVE ON CORROSION CONTROL CART.

I. ALLOW STARTER TO COOL NO LESS THAN 10 MINUTES AND REPEAT RINSE CYCLE, STEP H.

J. REMOVE CAP FROM CROSS BLEED LINE.

K. CONNECT HYDRAULIC PRESSURIZATION LINE TO CROSS BLEED LINE JUST AFT

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01	LOCAL T56-A-427 SPECIAL 28-DAY	ELEC PWR ON
WORK AREA	WORK UNIT CODE / C R S N / TIME 3.3	RTG. AD NO. 03 / MOS. NO.		HYD PWR N/A COND AIR OFF

DECU

L. REMOVE CAP AND CONNECT TORQUEMETER ANTI-ICING HOSE AND 5TH AND 10TH STAGE BLEED AIR HOSE.

M. REMOVE CAPS FROM THE FOLLOWING LINES:

1. DECU PS7 LINE TO DECU.
2. DECU COMPRESSOR INLET PRESSURE LINE TO COMPRESSOR TEE FITTING.
3. ANTI-ICING LINE TO COMPRESSOR DISCHARGE PRESSURE TRANSMITTER.

N. RESTORE CORROSION CONTROL CART TO ORIGINAL CONDITION AND SECURE.

O. WITH ALL SWITCHES IN NORMAL START POSITION AND POWER LEVERS AT GRD IDLE, OPERATE ENGINE IN ACCORDANCE WITH PROCEDURES IN WP009-00 FOR A MINIMUM OF 10 MINUTES.

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-76) S/N 0102-LF-604-7818 *SUPERSEDES NAVAIR FORM 4730/3 WHICH IS OBSOLETE.*

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01

P. OPERATE ENGINE ANTI-ICING IN ACCORDANCE WITH WP009-00 FOR A MINIMUM OF ONE MINUTE.

Q. AFTER ENGINE SHUTDOWN, CONNECT THE FOLLOWING LINES:

1. DECU PS7 LINE TO DECU.
2. DECU COMPRESSOR INLET PRESSURE LINE TO COMPRESSOR TEE FITTING.
3. COMPRESSOR DISCHARGE PRESSURE LINE TO TRANSMITTER.

R. INSTALL ENGINE ACCESS PANELS. (330, 340, 376 AND 350 FOR LEFT ENGINE, OR ITEMS 359, 363, 393, AND 400 FOR RIGHT ENGINE, NAVAIR 01-E2AAA-2-1, WP011-00).

S. PERFORM ENGINE PERFORMANCE CHECK AND TREND ANALYSIS IAW NA01-E2AAA-2-10, WP021-00.

NAVAIR 4790/3 (REV 7-76) (BACK)

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91				CHANGE NUMBER 01	LOCAL T56-A-427	ELEC PWR OFF
WORK AREA	WORK UNIT CODE	CRSN	TIME 3.3	RTG. AD NO. 03	MOS. NO.		HYD PWR N/A COND AIR OFF

M. FABRICATE AND INSTALL HOSE ASSEMBLY (MS28741-8-0120) OR EQUIVALENT TO END OF REDUCER FITTING ON WATER SUPPLY HOSE

N. SERVICE CORROSION CONTROL CART WITH A MIXTURE OF 1 PART B&B 3100 CLEANER AND 4 PARTS WATER IN QUANTITY SUFFICIENT TO FILL FORWARD COMPARTMENT (7 GALLONS) ON CART. FILL AFT COMPARTMENT (26 GALLONS) WITH WATER OF DRINKING PURITY.

O. POSITION CORROSION CONTROL CART OUTBOARD AND AFT OF ENGINE TO BE WASHED.

P. CONNECT CART SOLUTION SUPPLY HOSE (1/2-INCH) TO THREE-WAY FITTING AT FORWARD LEFT SIDE OF POWER SECTION AIR INLET HOUSING. DO NOT KINK HOSE.

Q. CONNECT AN AIR SOURCE SUFFICIENT TO SUPPLY 60 PSIG TO THE 5TH AND 10TH STAGE AIR BLEED HOSE ASSEMBLY.

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-70) S/N 0102-LF-604-7915

SUPERSEDES NAVAIR FORM 4730/J WHICH IS OBSOLETE.

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01

R. ON THE 65A102-J1-1 CART ENSURE QUICK ACTING VALVES ARE CLOSED AND THEN OPEN WATER SHUTOFF VALVE AND SOLUTION SHUTOFF VALVE

3 pen

WARNING

PROVIDE ADEQUATE NUMBER OF PERSONNEL FOR ENGINE TO BE WASHED; STATION FLIGHT CREW, GROUND COORDINATOR/ SAFETY OBSERVER AND CORROSION CONTROL CART.

CONDITION LEVERS ON QUADRANT MUST BE IN GROUND STOP POSITION TO PREVENT ENGINE LIGHTOFF DURING ENGINE MOTORING.

CAUTION

ENGINE MOTORING AND WASH CYCLE IS NOT TO EXCEED 60 SECONDS TIME PERIOD OR DAMAGE TO STARTER MAY OCCUR. BEFORE OPERATING CORROSION CONTROL CART, AIR PRESSURE REGULATOR SHALL BE SET FOR CORRECT PRESSURE OR EQUIPMENT MAY BE DAMAGED.

NAVAIR 4790/3 (REV 7-7) (BACK)

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91				CHANGE NUMBER 01	LOCAL T56-A-427	ELEC PWR OFF; HYD PWR N/A
WORK AREA	WORK UNIT CODE	C R S N	TIME 3.3	RTG. AD NO. 03	MOS NO.		COND AIR OFF

WARNING

DO NOT USE WATER/ALCOHOL MIXTURE IF AMBIENT TEMPERATURE IS OVER 4°C (40°F).

CAUTION

DO NOT ENERGIZE IGNITER DURING MOTORING.

WHEN USING WATER/ALCOHOL MIXTURE IT IS NECESSARY FOR FIRE-FIGHTING PERSONNEL/EQUIPMENT TO BE READY FOR FIRE WATCH AND CLEAN-UP.

3. OBSERVE PRECAUTIONS LISTED UNDER CORROSION ELIMINATION (NAVAIR 01-E2AAA-3-1, WP006-50) AND PROCEED AS FOLLOWS:

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-78) S/N 0102-LF-604-7915

SUPERSEDES NAVAIR FORM 4730/3 WHICH IS OBSOLETE.

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01

A. REMOVE ACCESS PANELS OF ENGINE TO BE CLEANED. (ITEMS 330, 340, 376, AND 380 FOR LEFT ENGINE, OR ITEMS 359, 363, 393, AND 400 FOR RIGHT ENGINE IN NAVAIR 01-E2AAA-2-1, WP011-00).

B. CHECK ENGINE COMPRESSOR INLET HOUSING AND STRUTS FOR FOREIGN OBJECT DAMAGE, CRACKS, CORROSION, AND SALT DEPOSITS.

C. CHECK INLET GUIDE VANES, STATOR VANES AND BLADES FOR FOREIGN OBJECT DAMAGE, CRACKS, CORROSION, AND SALT DEPOSITS.

D. CHECK ENGINE COMPRESSOR CASE FOR CORROSION.

E. ON OVERHEAT DETECT BLEED AIR PANEL, SET LEFT AND RIGHT BLEED AIR SWITCHES TO OFF, AND ENSURE LEFT AND [illegible]T

CARD	NAVAIR 01-000-6 NA01-' AA-6-3 DATE 01FEB91	CHANGE NUMBER 01	LOCAL ? A-427 SPECIAL 28-DAY	ELEC PWR OFF
				HYD PWR N/A
WORK AREA	WORK UNIT CODE	CRSN	TIME 3.3	RTG. AD NO. 03	MOS. NO.		COND AIR OFF

F. DISCONNECT AND CAP THE FOLLOWING LINES:

1. DECU COMPRESSOR INLET PRESSURE LINE AT COMPRESSOR TEE FITTINGS AND CAP WITH AN929-4K CAP.
2. DECU PS7 LINE FROM DECU, AND CAP WITH AN806-3K CAP.
3. COMPRESSOR DISCHARGE PRESSURE LINE FROM ANTI-ICE LINE, BETWEEN ANTI-ICE SHUTOFF VALVE AND DIFFUSER PORT AND CAP WITH AN929-4K CAP.

90FK

G. DISCONNECT TORQUEMETER SHROUD ANTI-ICE HOSE ASSEMBLY AT THREE-WAY FITTING, FORWARD LEFT SIDE OF POWER SECTION AIR INLET HOUSING.

10M

H. CONNECT SPRAYING UNIT WASH HOSE TO THREE WAY FITTING.

MAINTENANCE REQUIREMENTS CARD
NAVAIR 4790/3 (REV 7-76) S/N 0102-LF-004-7915

SUPERSEDES NAVAIR FORM 4730/3 WHICH IS OBSOLETE.

CARD	NAVAIR 01-000-6 NA01-E2AAA-6-3 DATE 01FEB91	CHANGE NUMBER 01

I. DISCONNECT 5TH AND 10TH STAGE AIR BLEED HOSE AT SPEED SENSITIVE VALVE ON LEFT SIDE OF POWER SECTION ACCESSORY DRIVE AND CAP PORT ON SPEED SENSITIVE VALVE DURING WASH.

J. OPEN STRAPS AT FORWARD END OF CORROSION CONTROL CART AND PULL OUT 1/2-INCH SOLUTION SUPPLY HOSE AND REMOVE QUICK DISCONNECT SOCKET, PART NO. (HANSEN 500 AND NIPPLE) AND ADAPTER, PART NO. AN816-8D1. RETAIN PARTS.

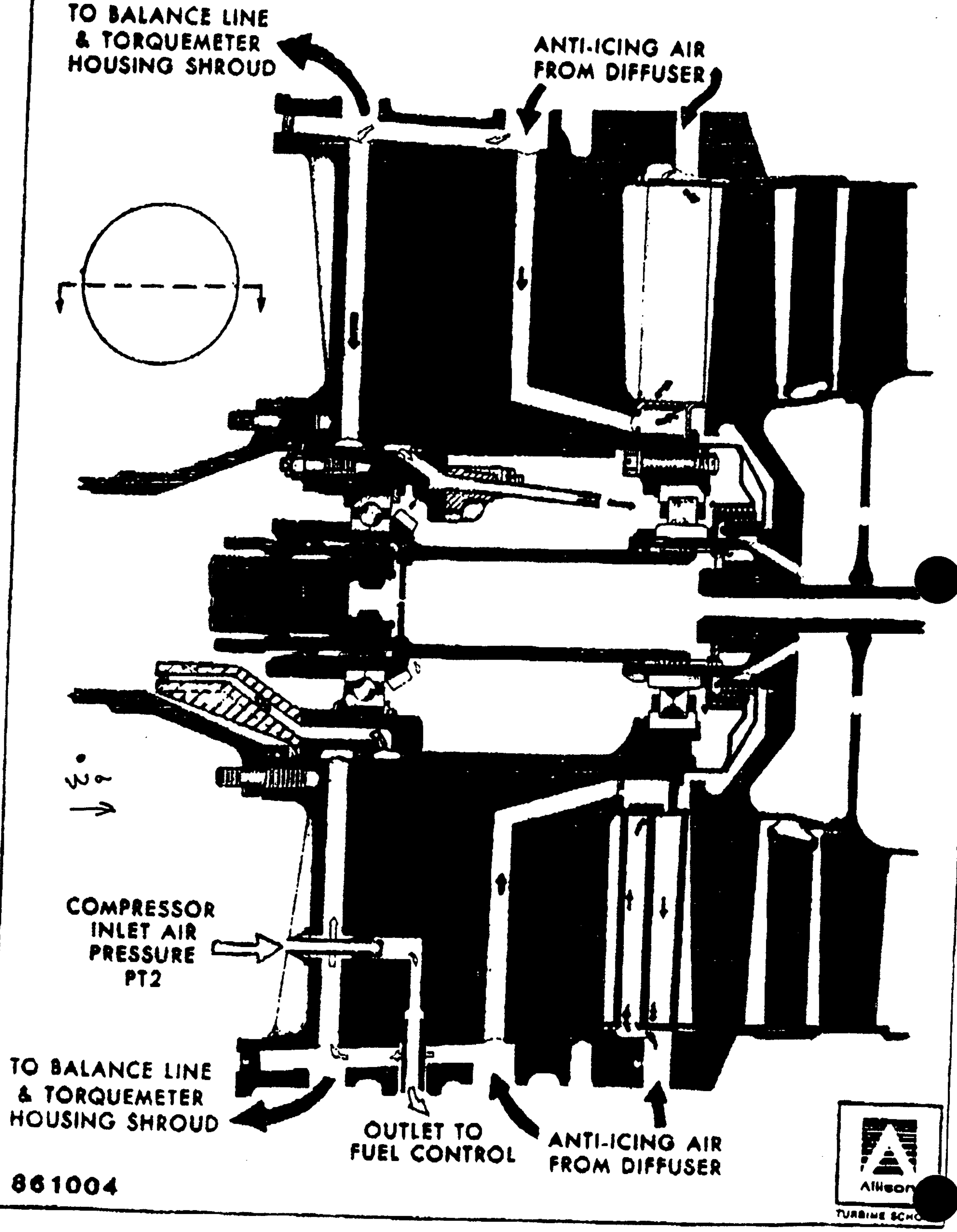
K. OPEN STRAPS AT AFT END OF CORROSION CONTROL CART AND PULL OUT 1-INCH WATER SUPPLY HOSE AND REMOVE QUICK DISCONNECT SOCKET, PART NO. (HANSEN 540) AND ADAPTER AN816-16-12D1. RETAIN PARTS.

L. INSTALL REDUCER FITTING (AN919-29D) INTO END OF 1-INCH WATER SUPPLY HOSE.

NAVAIR 4790/3 (REV 7-76) (BACK)

SCHEMATIC COMPRESSOR AIR INLET HOUSING

501-D13,-D22,-D22A
T56-A-7B,-15,-10W



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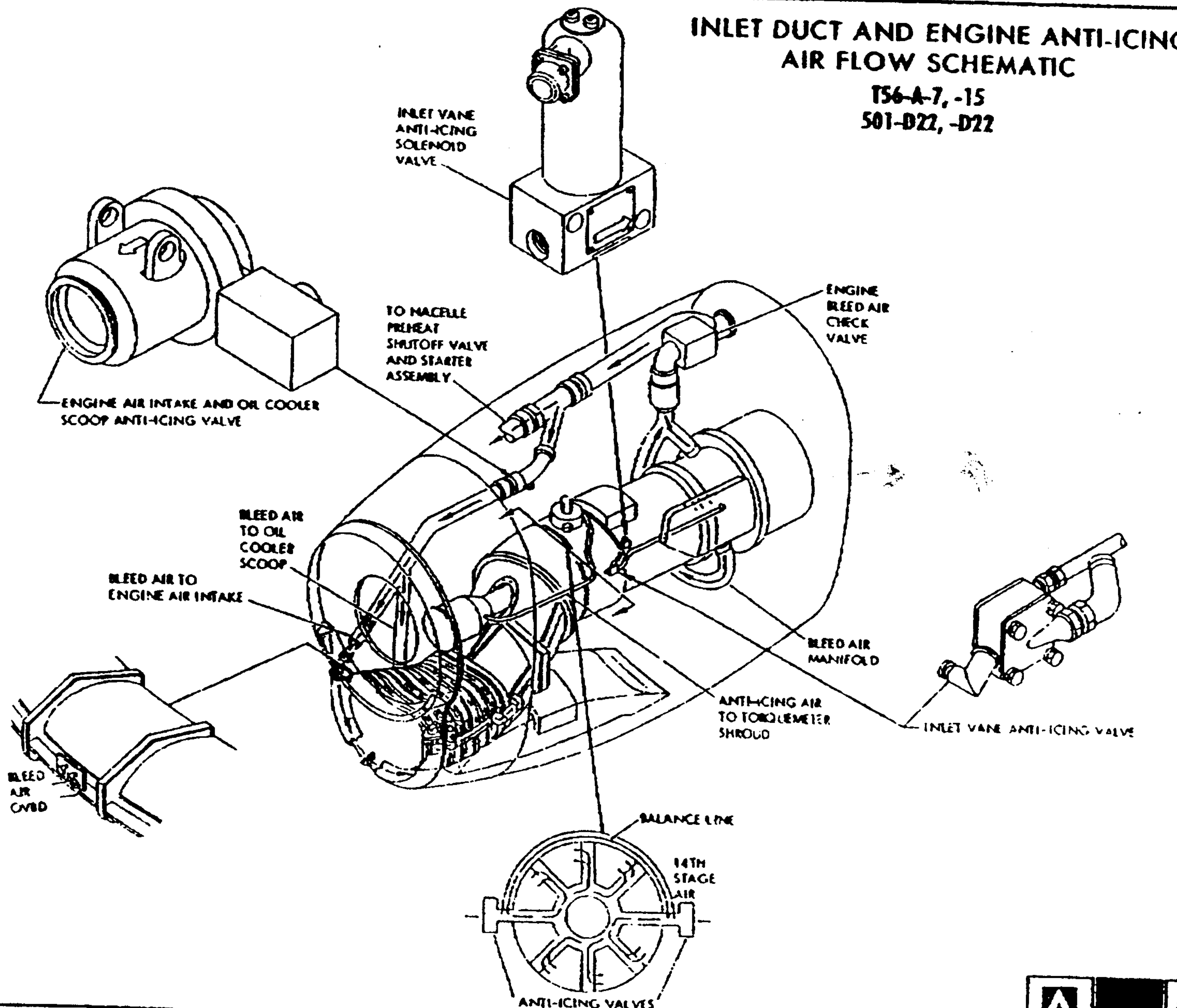
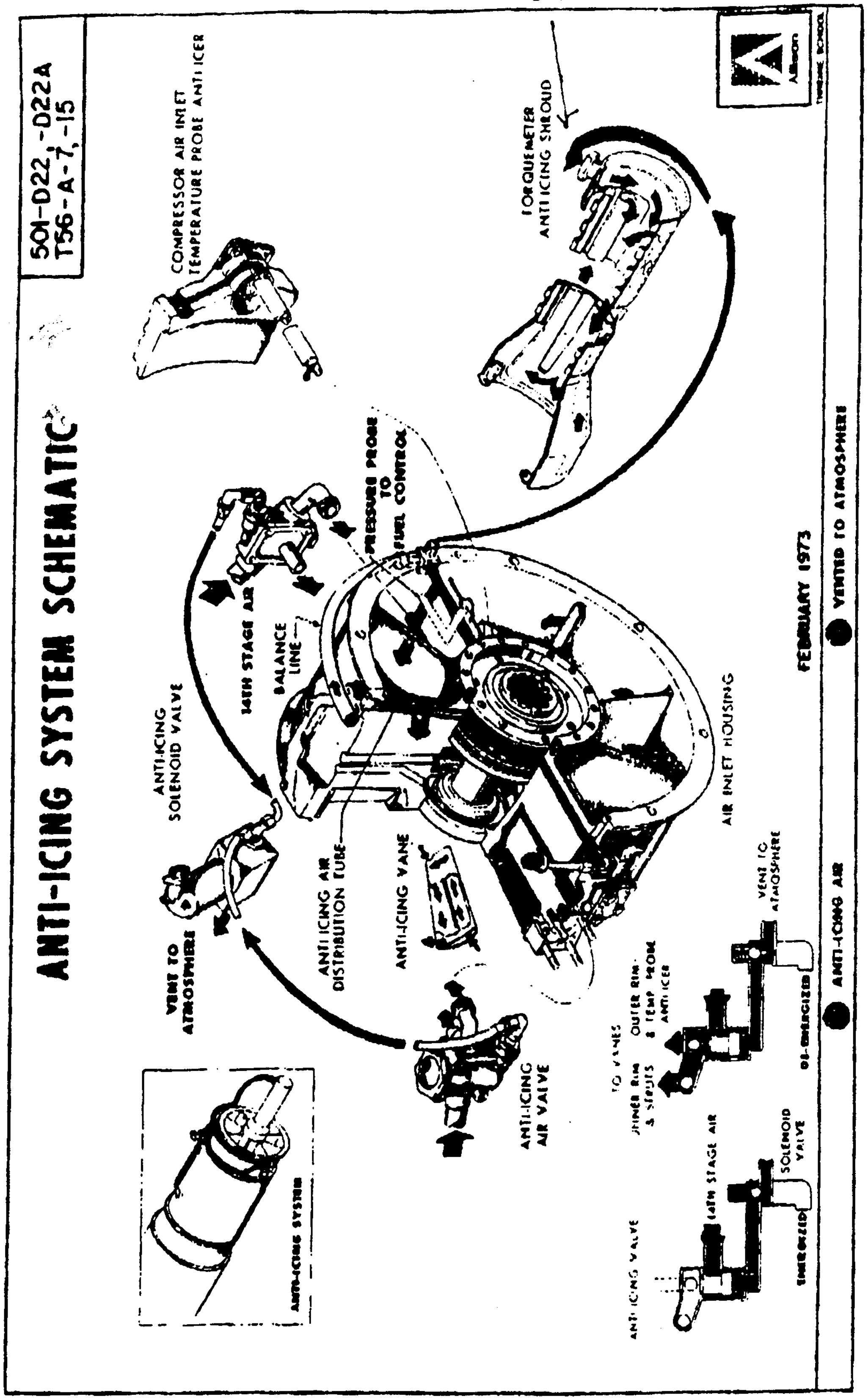
INLET DUCT AND ENGINE ANTI-ICING AIR FLOW SCHEMATIC

T56-A-7, -15
501-D22, -D22



T56-104

Correct cast lined line



3-799. Corrosion pits in the rear flange area exceed 0.100 in. depth.

3-800. ENGINE COMPRESSOR CLEANING.

3-801. GENERAL.

3-802. Checkout and troubleshooting procedures are performed as follows:

3-803. Operational check of engine systems follows normal engine operating sequence through prestart and start procedures, except that sequence shall be interrupted if abnormal conditions or abnormal instrument indications occur. At that time, troubles shall be located and corrected before proceeding.

3-804. During checkout procedure all engine systems are operated and instrument indications noted. Again system operating sequence shall be interrupted if abnormalities in operation or instrument indication occur and troubles shall be corrected before continuing with system operating sequence.

3-805. Perform safety check before maintenance.

3-806. ENGINE COMPRESSOR CLEANING ENGINE MOTORING.

3-807. To clean the engine compressor, proceed as follows:

CAUTION

If engine has been running, allow to cool for a minimum of 45 minutes or until turbine temperature indicator reads 70°C or less. Do not attempt to clean engine if outside air temperature is 4.4°C (40°F) or below.

NOTE

If recent performance data on engine is not available, and water wash effect on engine performance is desired, perform engine efficiency run (NAVAIR 01-E2AAA-2-10, WP 022 00) and record all engine operating data on engine ground run form.

3-808. RECLEANING.

3-809. Observe precautions listed under Corrosion Elimination (NAVAIR 01-E2AAA-3-1, WP 006 50) and proceed as follows:

3-810. Remove access panels of engine to be cleaned.

NOTE

Corrosion may occur when salt deposits from sea water ingestion or environmental atmospheric conditions are allowed to remain on compressor parts. Prompt removal of salt deposits will prevent corrosion and corrosion related compressor blade and vane failures.

3-811. Check engine compressor inlet housing and struts for unacceptable foreign object damage, cracks, or corrosion.

3-812. Check air inlet guide vanes, stator vanes and blades for unacceptable foreign object damage, cracks, or corrosion.

3-813. On OVERHEAT DETECT BLEED AIR panel, set LEFT and RIGHT BLEED AIR switches to OFF, and insure LEFT and RIGHT condition levers on quadrant are positioned to GRD STOP.

NOTE

Perform steps 3-814 through 3-817 for shore-based aircraft using 76E04000-30 spraying unit, and steps 3-818 through 3-828 for shipboard corrosion control cart 65A102-J1-1. If neither cart is available, refer to paragraph 3-846.

3-814. Service spraying unit with B&B 3100 cleaner and fresh water. (4 parts water to one part cleaner.)

3-815. Position spraying unit outboard and aft of engine to be washed.

3-816. Disconnect torquemeter shroud anti-ice hose assembly at fitting, forward left side of power section air inlet housing. Connect spraying unit (figure 3-59) wash hose to fitting.

3-817. Disconnect 5th and 10th stage air bleed hose at speed sensitive valve on left side of power section accessory drive and cap port on speed sensitive valve during wash. Connect spraying unit air hose to air bleed hose assembly. Start spraying unit and continue procedures in paragraphs 3-829 - 3-845.

NOTE

If corrosion control cart 76E04000-30 is not available, the following procedure is acceptable with the 65A102-J1-1 cart (see figure 3-60).

3-818. Open straps at forward end of corrosion control cart and pull out 1/2-inch solution supply hose and remove quick disconnect socket, part no. (hansen 500, and nipple), and adapter, part no. AN816-8D1 (see figure 3-60). Retain parts.

3-819. Open straps at aft end of corrosion control cart and pull out 1 inch water supply hose and remove quick disconnect socket, part no. Hansen 540, and adapter AN816-16-12D1 (see figure 3-60). Retain parts.

3-820. Install reducer fitting (AN919-29D) into end of 1 inch water supply hose.

3-821. Fabricate and install hose assembly (MS28741-8-0120) or equivalent to end or reducer fitting (AN919-29D) on water supply hose.

3-822. Service corrosion control cart with a mixture of 1 part B&B 3100 cleaner and 4 parts water in quantity sufficient to fill forward compartment (7 gallons) on cart. Fill aft compartment (26 gallons) with water of drinking purity.

3-823. Position corrosion control cart outboard and aft of engine to be washed.

3-824. Disconnect torquemeter shroud anti-ice hose assembly at fitting located on forward left side of power section air inlet housing.

3-825. Connect cart solution supply hose (1/2 inch) to above fitting. Do not kink hose.

3-826. Disconnect 5th and 10th stage air bleed hose assembly at speed sensitive valve (figure 3-68). Cap port on speed sensitive valve during wash.

3-827. Connect an air source sufficient to supply 60 psig to the 5th and 10th stage air bleed hose assembly.

3-828. On the 65A102-J1-1 cart make sure quick acting valves are closed and then open water shutoff valve and solution shutoff valve.

WARNING

Provide adequate number of personnel for engine to be washed; flight station crew, ground coordinator/safety observer and spraying unit, corrosion control cart or spray mix applicator operator.

Condition levers on quadrant must be in GRD STOP Position to prevent engine lightoff during engine motoring.

CAUTION

Engine motoring and wash cycle is not to exceed 60 seconds time period or damage to starter may occur. Before operating spraying unit, corrosion control cart or spray mix applicator air pressure regulator shall be set for correct pressure or equipment may be damaged.

NOTE

When using cleaning solution, air pressure regulator shall be set for pressure required to obtain flow rate of 3.0 gallons per minute (approximately 4 to 6 psig). When using water rinse, air pressure regulator shall be set for 4 to 6 psig.

3-829. ENGINE WASH PROCEDURE.

3-830. To wash the engine, proceed as follows:

WARNING

Spraying unit and operator must be in full view of personnel operating engine controls. Propeller must be in start angle position.

3-831. Connect external electrical power to aircraft via external power receptacle no. 1 t Sta 350 (R side).

3-832. Connect pneumatic starting unit to ground-start connections in right main wheel well for right engine or left main wheel well for left engine. (See figure 3-61.)

WARNING

Condition lever must be in GRD STOP position during engine motoring to prevent engine light off.

3-833. When using 76E04000-30 spraying unit, obtain operating pressure of 100-120 psig and then open spraying unit valves to pressurize water tank and air line to air bleed valves which close engine compressor 5th and 10th stage air bleed valves. When using 65A102-J1-1 cart turn on air source to supply 60 psig to the 5th and 10th stage air bleed hose assembly.

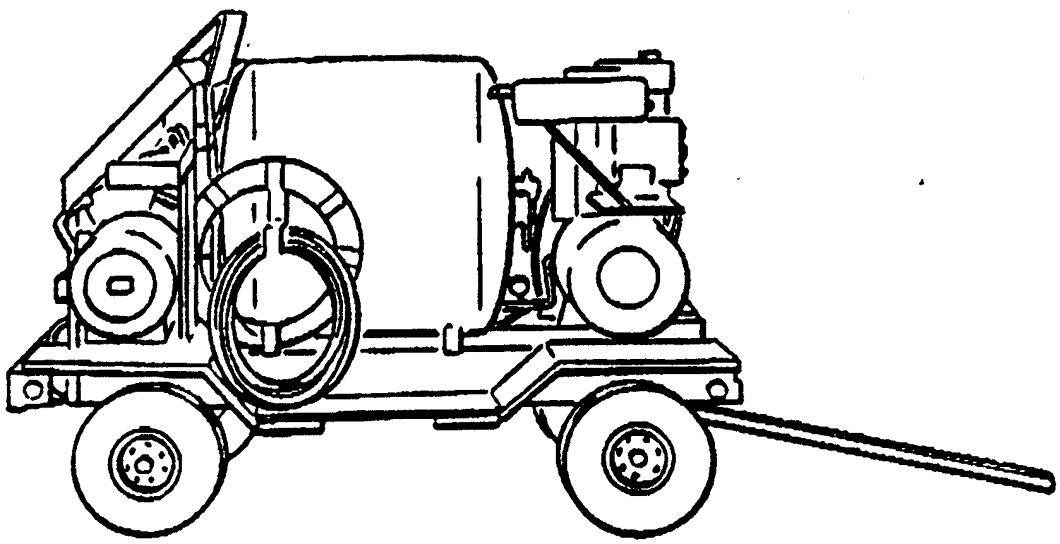


Figure 3-59. Spraying Unit, 76E04000-30

NOTE

Use stop watch to monitor engine to be motored for 60 second wash cycle.

3-834. With propeller arc clear of obstructions, and power levers to GRD IDLE and condition levers to GRD STOP, motor engine by holding GRD START switch on ENGINE CONTROL PANEL to L or R and start stop watch.

3-835. Open valve on spraying unit or quick acting solution valve on corrosion control cart to allow a wash mixture to pass through engine as engine begins to rotate.

NOTE

Spraying unit air pressure should not drop below 25 psi during wash cycle.

3-836. Terminate engine wash and motoring by releasing GRD STOP switch after 60 seconds; allow starter to cool and solution to soak for a minimum of 10 minutes. Close valve on unit to stop wash mixture.

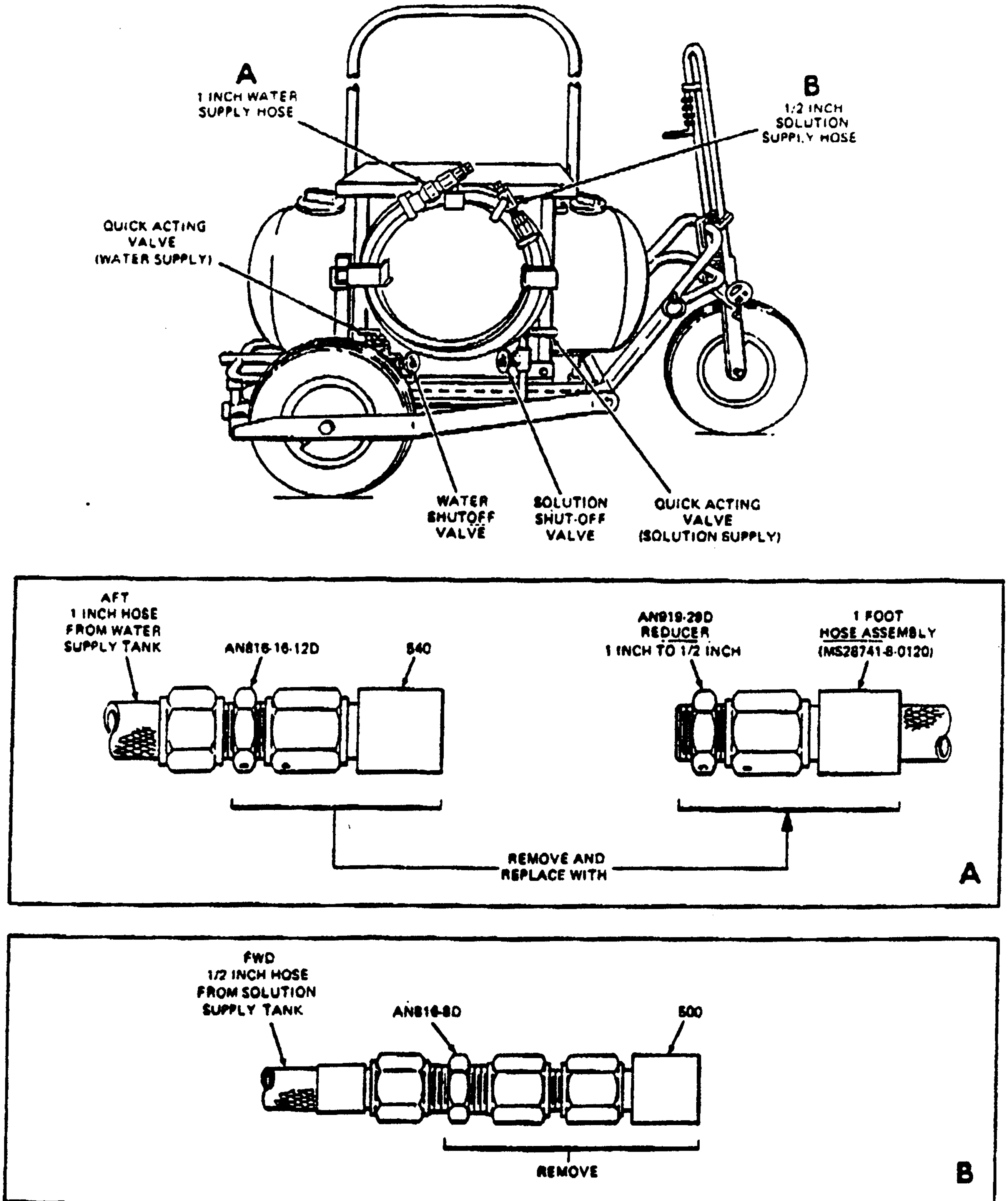


Figure 3-60. Corrosion Control Cart, 65A102-J1-1

T18 Goes On

NOTE

When using 65A102-J1-1 cart, remove solution supply hose and connect water supply hose to three way fitting before starting double rinse cycle.

3-837. Repeat steps 3-827 through 3-833 without B&B 3100 cleaner to perform wash rinse cycle. Allow only fresh water to flow through engine by opening fresh water valve on spraying unit or quick acting water valve on corrosion control cart.

3-838. Allow starter to cool no less than 10 minutes and repeat rinse cycle.

NOTE

If engine does not shut down, set condition lever to FEATH.

WARNING

Do not disconnect pneumatic air connection hose without protective gloves.

3-839. Shut down spraying unit electrical and pneumatic power source and disconnect spraying unit.

3-840. Remove cap and connect torquemeter anti-icing hose and 5th and 10th stage air bleed hose. Restore aircraft to normal condition.

3-841. Restore spraying unit to original condition and secure.

3-842. With all switches in normal start position and power levers at GRD IDLE, operate engine for a minimum of 10 minutes.

3-843. Operate engine anti-icing for a minimum of 1 minute.

3-844. Perform engine performance check and trend analysis.

3-845. If results are not satisfactory, perform walnut-shell cleaning procedures per paragraph 3-881.

3-846. ENGINE WASH-ALTERNATE PROCEDURE.

3-847. The following procedure is for engine wash when neither 76E04000-30 spraying unit nor 65A102-J1-1 corrosion control cart is available.

NOTE

If units are not available, the engine wash may be accomplished with the model 299 or 299C spray mix applicator. The applicator must be modified for the E-2C aircraft.

3-848. Perform steps 3-840 through 3-869.

3-849. Modify applicator by removing applicator hose (figure 3-62) with fittings and installing adapter fitting (AN816-8D) into check valve.

3-850. Install fabricated MS28741-8-2400 hose assembly into adapter fitting.

3-851. Positions 5 gallon drum or equivalent with B&B 3100 cleaner outboard and aft of engine.

3-852. Install modified spray mix applicator in drum and loosen 3/4-inch bung in top of drum to permit air to enter drum.

3-853. Disconnect torquemeter shroud anti-ice hose assembly at three-way fitting located at forward side of power section air inlet housing.

3-854. Connect an air source sufficient to supply 60 psig to the 5th and 10th stage air bleed hose assembly. Cap port on speed sensitive valve during wash. Do not kink or put tension on hose.

3-855. Provide a pressure source of water of drinking purity.

3-856. Water pressure must be 25 psig minimum and 150 psig maximum.

3-857. With water control valve lever in OFF position, connect water source to water inlet hose adapter (figure 3-62).

CAUTION

Insure water pressure is between 25 and 150 psig to avoid damaging equipment.

3-858. Perform steps 3-831 and 3-832. Observe warning, caution, and note following paragraph 3-828.

3-859. Turn on pressure source to approximately 60 psig and turn on water source.

3-860. Turn chemical control valve located just above drum to ON by putting lever straight up or down.

NOTE

Propeller blades shall be in start position (start blade angle).

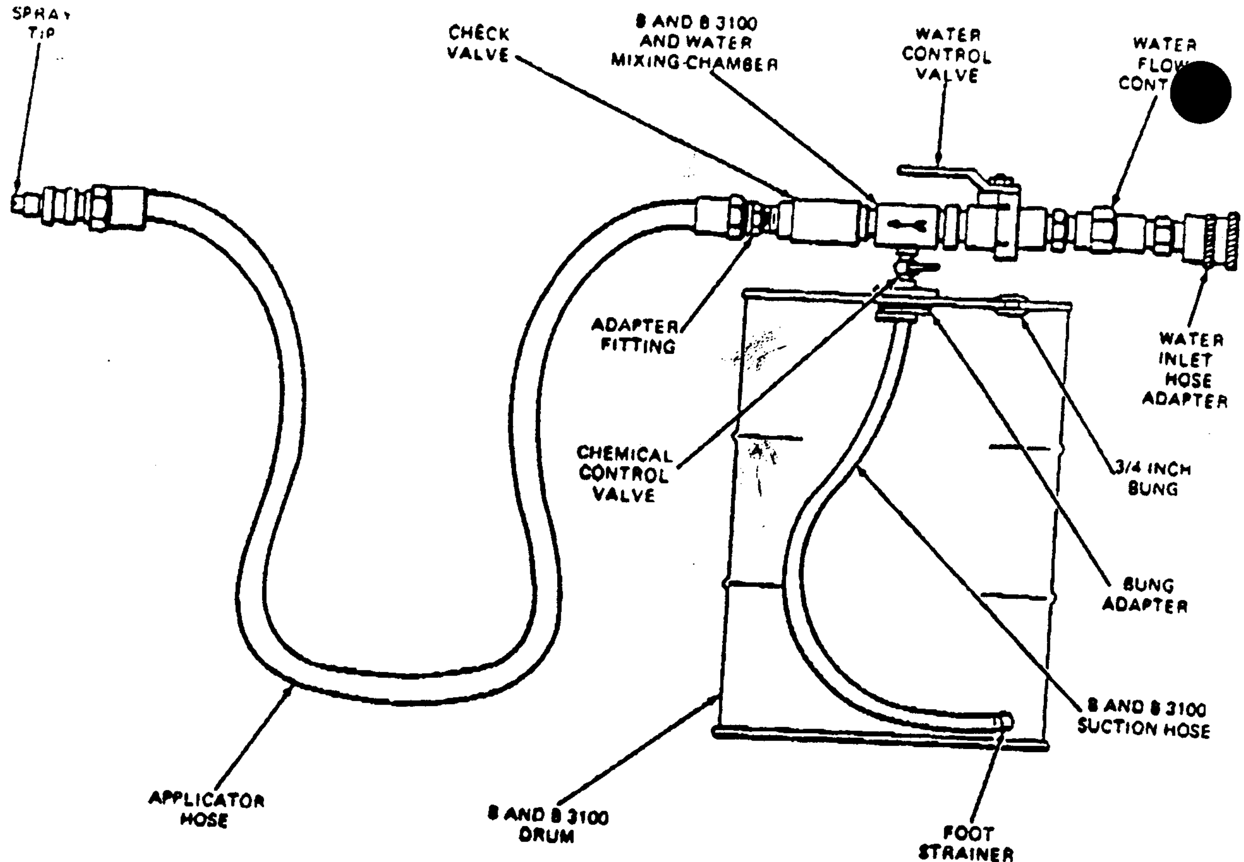


Figure 3-62. Spray Mix Applicator Hook Up

3-861. Insure propeller arc is clear of obstruction and power levers are in GRD IDLE and condition levers on quadrant are in GRD STOP.

3-862. Open applicator control valve and signal cockpit personnel to motor engine using GRD START switch on ENGINES control panel. As propeller begins to rotate, open water control valve on applicator and allow to flow for 60 seconds. Turn off water control valve. Shut down engine and let starter cool.

3-863. Let solution soak for a minimum of 10 minutes.

3-864. On applicator, turn chemical control valve to OFF to eliminate chemicals and repeat steps 3-861 and 3-862 for two rinse cycles.

3-865. Disconnect applicator water inlet hose and air source.

3-866. Tighten 3/4-inch bung on top of drum and move applicator and drum away from aircraft.

3-867. Restore speed-sensitive valve to normal by removing cap and connecting 5th and 10th stage air bleed hose assemblies.

3-868. Connect torquemeter shroud anti-ice hose assembly at three-way fitting.

3-869. Store parts removed from applicator on modified rig and leave in modified stage for future use.

3-870. Perform procedures in paragraphs 3-842 and 3-843.

3-871. BURNER FUEL DRAIN VALVE.

3-872. REMOVAL.

3-873. Remove nacelle access cover to engine igniter.

3-874. Disconnect lines from forward and aft valves.

3-875. Remove lockwire and bolts that secure forward valve to combustion section housing and remove valve and gasket. Discard gasket.

3-876. Repeat step 3-875 to remove aft valve.

3-877. INSTALLATION.

3-878. Apply a light coat of anti-seize compound (MIL-L-25681) to valve mounting bolts.

Description of the Wingship Technical Evaluation Team (WTET)

CONTENTS

Appendix I

Participants

LtCol Michael S. Francis	Program Manager
Roger Gallington (SAIC)	Technical SETA
Glenn Goodman (SRS Tech)	Support SETA
Capt. Ed Pope, USN, OCNR	Navy Liaison / Russian POC
John Fraas, USN, ONR-SOP	Navy Liaison

Technical Evaluation Team

Bob Wilson, DTRC	WIG Expert
Joe Gera, NASA - Dryden	Flight Controls
Burt Rutan, Scaled Composites	Structures / Aircraft Design
Len Malthan, Northrop	WIG Designer
John Reaves, NAWC - AD (Warminster)	WIG Expert
Stephan Hooker (Aerocon)	WIG Expert/ Historical Database
Dr. Eugene Covert	Aeronautics Expert/Aerodynamicist
Hal Fluk, NAWC-AD (Lakehurst)	Infrastructure/Support
Eric Lister, SRS Technologies	Propulsion Expert
Jim Camp, DTRC	WIG Specialist
Dieter Czimmek, Newport News Shpbldg	Ship Structures
Dan Savitsky, Stevens Inst.	WIG Tester
C.F. Snyder, DTRC	Mission Analyst (Sealift)

LT COL MICHAEL S. FRANCIS

Lt Col Francis is the Program Manager for the X-31 Enhanced Fighter Maneuverability Demonstrator Program for the Advanced Research Projects Agency (or ARPA). He serves in this capacity for several programs, including the X-31 Enhanced Fighter Maneuverability Demonstrator Program, the Wingship Investigation, and a DoD-sponsored study on Aircraft Affordability. The X-31 is the latest experimental, high performance aircraft, developed to pioneer agile flight beyond the aerodynamic stall barrier. This international collaborative program between the United States and Germany is in its flight test phase. The Wingship Investigation is assessing the technical feasibility and operational utility of very large wing-in-ground effect vehicles employed in a variety of defense missions. The Aircraft Affordability Study is oriented at applying advanced technology in the aircraft acquisition process, including the development and operational phases.

Lt Col Francis received his Bachelor of Science degree in Aerospace Engineering Sciences from the University of Colorado in 1969 and was commissioned as an officer in the U.S. Air Force. He entered graduate school at the University of Colorado where he completed Master of Science and Doctoral programs, also in Aerospace Engineering Sciences. Lt Col Francis entered active duty in March, 1974. Assigned to the Frank J. Seiler Research Laboratory, Colorado, he engaged in unsteady aerodynamics research and served as a lecturer in the Department of Aeronautics. While at the Academy, he conducted the first investigations of dynamic lift on airfoils undergoing rapid, large amplitude arbitrary pitching motions. He was next assigned a Program Manager, Air Force Office of Scientific Research, Bolling AFB, Washington D.C. where he managed Air Force basic research programs in aerodynamics and turbulence structure. Following completion of the Program Management Course at the Defense Systems Management College in the fall of 1984, he was assigned to the Air Force Space Systems Division, Los Angeles AFB, California, where he served a program manager in several space R&D programs. Lt Col Francis is an associate fellow of the American Institute of Aeronautics and Astronautics (AIAA), and is currently serving his second term on that organization's Board of Directors. He is a member of the American Society of Mechanical Engineers (ASME) and the Air Force Association. He also served on the NASA Advisory Committee for Aeronautics and has been a reviewer for several journals. He has authored or co-authored over 30 open literative publications.

ROGER W. GALLINGTON

Roger W. Gallington manages a division of Science Applications International Corporation (SAIC) in Seattle. He uses structured group methods and statistical tools to evaluate technology and technical risk in results-oriented research and development programs. Prior to joining SAIC, Dr. Gallington was a Test Engineering Manager at Martin Marietta Aerospace in Denver. He served in the Air Force with his last assignment as Director of the Aeronautics Laboratory and Tenure Associate Professor at the USAF Academy.

From 1975 through 1978, Dr. Gallington worked, along with others, at the (then) David Taylor Research Center to develop most of the published western-world information on the power augmented ram (PAR) feature which is prominent in many current Russian designs. Prior to that, he tested model wing-in-ground effect vehicles in wind tunnels, over ground, and over water. He took some of the best photographs ever taken of vortex shedding from the bottom of the end plate of a wing in strong ground effect.

Dr. Gallington earned his Ph.D. in Aeronautical Engineering from the University of Illinois in 1967.

CAPT EDMOND D. POPE

Capt Ed Pope graduated from Oregon State University with a B.A. (mathematics) in 1969. Capt Pope was selected as a career designated naval intelligence specialist in 1973. Significant tours include a deployment to southeast Asia aboard USS ORISKANY and staff tours with CINCPACFLT, CNO, and COMSIXTHFLT in Gaeta, Italy. He then served as Assistant Naval Attache, Stockholm, Sweden in the early 1980's when a Soviet WHISKEY class submarine ran aground there and has recently completed three tours in the Pentagon, the longest being in the Office of Assistant Secretary of the Navy (Research, Development and Acquisition).

Upon reporting to the Office of Naval Research in 1991, he established the Science Opportunities Program (SOP) which is an effort to identify unique science and technology from republics of the Former Soviet Union. Under this program, he has participated and organized numerous successful efforts, including transition of advanced materials technologies, academic assistance programs, procurement of unique Russian devices, and numerous other related activities. In September of 1992, he visited Russia and identified numerous technologies of potential interest, including ocean acoustics, Wing-In-Ground effect (WIG) vehicles, laser/lidar systems, propulsion systems, etc. He has established excellent relationships with numerous key Russian and Ukranian authorities and continues activities under the SOP on a near-full time basis at ONR.

Born in San Diego, California, Capt Pope was raised in Grants Pass, Oregon where his parents still reside. His hobbies include snow skiing, scuba diving, photography, woodworking, boating and jogging.

Capt Pope is married to the former Cheryl I. Thompson of San Diego, California. Capt and Mrs. Pope have two sons.

JOSEPH GERA

Mr. Gera earned his Masters Degree in Applied Mechanics at the University of Virginia in 1965. He has met the course requirements for a Ph.D at North Carolina State University.

Mr. Gera has had a distinguished career with NASA leading to National recognition for his flight controls expertise. From 1962 through 1979 he did wind tunnel testing, trajectory optimization, and aircraft dynamics and control at the NASA Langly Research Center. From 1979 to the present, Mr. Gera has been at the NASA Ames Research Center/Dryden Flight Research Facility engaged in flight controls research including high angle of attack handling qualities. He was the lead flight controls engineer on the X-29A Forward Swept Wing Demonstrator flight tests. He consulted on the X-31 Enhanced Fighter Maneuverability demonstrator for NASA. He is currently the Branch Chief of Dynamics and Controls Branch at the Dryden Facility. His organization includes 55 engineers working on flight test engineering, control laws, systems, and structural dynamics.

Mr. Gera has authored 29 papers and NASA reports on experimental aerodynamics, trajectory optimization, flight mechanics, and controls.

BURT RUTAN

Elbert (Burt) Rutan was raised in Dinuba, California. He received his Bachelor of Science degree in Aeronautical Engineering at California Polytechnic University in 1965. His course work also included classes at the Space Technology Institute, California Institute of Technology, marketing and personnel management courses in business administration from Golden Gate College, and classes in the Aerospace Research Pilot's School at Edwards Air Force Base. Mr. Rutan holds, in addition, the honorary degree of Doctor of Science from California Polytechnic State University, San Luis Obispo, dated 13 June 1987; Doctoral of Science, *honoris causa*, from Daniel Webster College, 17 May 1987; Doctoral of Humanities, *honoris causa*, from Lewis University, 22 May 1988 and Doctorate of Technology, *honoris causa*, from Delft University of Technology, 12 January 1990.

Mr. Rutan worked from 1965 until 1972 as Flight Test Project Engineer at Edwards Air Force Base, California. Then in March 1972, he became director of the Bede Test Center for Bede Aircraft in Newton Kansas.

In June of 1974, at Mojave, California, Mr. Rutan formed the Rutan Aircraft Factory (RAF) to develop light aircraft, and to market technical and educational documents. Through this company, the VariViggen, VariEze, NASA AD-1, Quickie, Defiant, Long-EZ, Grizzly, scaled NGT trainer, Solitaire, Catbird, and the world-flight Voyager aircraft were developed.

In April 1982, Mr. Rutan founded Scaled Composites, Inc. (Scaled) to develop research aircraft. These have included the Microlight aircraft developed for Lotus, the 85% scale Starship for Beech Aircraft Corporation, the Predator agricultural aircraft for Advanced Technology Aircraft Corporation, the CM-44 UAV for California Microwave, Inc., the Scarab Model 324 reconnaissance drone for Teledyne Ryan Aeronautical, and the ATTT Advanced Technology Tactical Transport for DARPA. These prototype aircraft were designed, fabricated and flight tested at the Scaled facility in Mojave, California. The high technology wing sails for the *Stars and Stripes* 1988 America's Cup Challenge Race were fabricated at the Scaled facility. Other Scaled projects include a light business turbofan, a close air support aircraft, and unlimited class air racer and the flying surfaces for orbital Sciences Corporation's Pegasus space launch vehicle. Currently, Scaled is fabricating a high altitude vehicle which will fly by the year's end and a project for McDonnell Douglas Space Systems Division - a 30% scale vehicle for the single-stage rocket technology (SSRT) Delta Clipper Program.

Mr. Rutan has extensive pilot experience.

A few of the awards which Mr. Rutan has received include:

- EAA Outstanding New Design, 1975, 1976 and 1978.
- Presidential Citizen's Medal presented by Ronald Reagan, December 29, 1986.
- Grand Medal of the Aero Club of France, January 29, 1987.
- National Acronautic Association and the National Aviation Club, 1987 Collier Trophy.
- Society of Experimental Test Pilots, 1987 J.H. Doolittle Award.
- Royal Aeronautical Society, British Gold Medal for Aeronautics, December 1987.
- *Design News* Engineer of the Year for 1988.
- Western Reserve Aviation Hall of Fame, Meritorious Service Award, 2 September 1988.
- The International Aerospace Hall of Fame Honoree, 24 September 1988.
- Member, National Academy of Engineering, 1989.

LEONARD V. MALTHAN

Mr. Malthan is an Advanced Design Manager who has served as project engineer and program manager of a number of future weapon systems. His early specialty was in aerodynamics when he was the initial Principal Investigator for the USAF Stability and Control DATCOM. His industry background spans 1 year each at Boeing and North America Aviation, 31 years at McDonnell Douglas and 9 years at Northrop.

His advanced design background includes NASA Span Loader, C-5A, C-117, F-15, S3A, various SAR programs and rapid transit studies.

In 1968 Mr. Malthan managed a project to design and build a sizeable double jet, fully controllable air cushion demonstrator vehicle under company funding. This work included hydrodynamic and aerodynamic testing. During this program an alternate concept emerged based on a tandem wing catamaran design. This project replaced the air cushion concept because of its superior efficiency and a 50 foot span test vehicle was built. This vehicle experienced a subsequent accident and the project terminated. Related program activities included a proposal design for an ONR assault GEM and a subcontract on a MARAD GEM.

Mr. Malthan also performed one of the initial performance assessments of the Soviet KASP A vehicle. He then managed a PAR study for the Navy ANVCE program.

Education includes a B.S. from John Hopkins University and an M.S. from the University of Southern California, both in Aeronautical Engineering.

JOHN M. REEVES

John Reeves was educated at the Kingston-upon-Hull and Kingston-upon-Thames Colleges of Technology where he received a Higher National Certificate in Mechanical Engineering and a Post Graduate Diploma in Aeronautical Design and Development, respectively. Served a five year apprenticeship with Blackburn Aircraft, Brought, East Yorks., from 1958 to 1963. This apprenticeship included hands-on manufacturing and assembly experience in tool room, machine shop, detail fitting, aircraft subassembly, aircraft final assembly. Engineering and design experience included, supersonic wind tunnel, stress analysis, flight test, data analysis, design office and aerodynamics department primarily on the Buccaneer and its planned follow-ons.

In late 1963 he joined Hawker Aircraft as aerodynamicist primarily working on the performance and configuration development of the Hawker Kestrel and HS-1154 supersonic V/STOl aircraft. Following cancellation of the HS-1154 he joined British Aircraft Corporation as an aerodynamicist working on configuration aerodynamics including wind tunnel testing and performance of the TSR-2, Super VC-10, BAC-1-11, Concorde and WIG and other projects.

After cancellation of the TSR-2 and lack of support for 265 seat development of the Super VC-10, John joined Grumman Aerospace as an aerodynamicist in 1968. His assignments included performance and configuration assessment of the A-6E, F-14, Tracked Air Cushion Vehicle, C-2, studies including PHM, DBH and DEH (1,000 ton) hydrofoil projects. He was responsible for the design of the Flagstaff II foil system. He was team leader for unsteady lift tow tank tests at David Taylor Research Center, and Grumman Whirling tank tests. He developed a theory which assisted in curing the loss of control following a hydrofoil broach.

In 1975 he left Grumman and joined a consulting company in Washington to support the Advanced Naval Vehicle Concept Evaluation Study in the hydrofoil technology evaluation. He joined the professional staff of the Center for Naval Analyses in 1980 and served as study director for the Center's ship, submarine and advanced craft conceptual design and cost models.

John joined NAWC(AD) Warminster in 1983. From 1985 to 1989 he was the Branch Head for the Weapon's System Cost Analysis Branch before moving to his present position. He is the air vehicle project leader for aircraft modification studies and for advanced air platform assessments. He was the project leader for two NAVSEA SYSCOM studies on Wing-In-Ground Effect platform assessments.

John commenced his WIG work in 1962 but pursued it no further after his analyses at Grumman Aerospace (1970) showed that such platforms could not compete with aircraft if only an induced drag reduction occurred in surface effect. In the U.K., he built a total of 24 free flight models of WIG's, conducted wind tunnel tests of a WIG in the mid-1960's, and built a manned model of WIG. In 1991, in the U.S., he flew an advanced hybrid-WIG model for which he has 8 patents pending with the U.S. Navy.

EUGENE E. COVERT

Dr. Covert is the T. Wilson Professor of Aeronautics (an endowed chair) at the Massachusetts Institute of Technology (MIT). He earned his Doctor of Science degree at MIT in 1958. After becoming the Associate Director of the Astrophysics Lab in 1963, he joined the academic faculty. He became a full professor in 1968 and served as Aeronautics and Astronautics Department Head from 1985 to 1990. He was Chief Scientist of the U.S. Air Force from 1972 to 1973 and Technical Director of the European Office for Research and Development from 1978 to 1979.

He serves as a director on the boards of: Allied Signal; Physical Sciences, Incorporated; Rohr Industries, Incorporated; and American Institute of Aeronautics and Astronautics.

He is frequently called to serve on national boards and committees. He is currently on the U.S. Scientific Advisory Board and served as its chairman from 1982 to 1986. He was on the NASA Aeronautics Advisory Committee from 1985 to 1989. He was on the Presidents Office of Science and Technology Policy form 1983 to 1988. He currently serves on the National Research Council Committee on NASA Program Changes and the Aeronautics and Space Engineering Board and chaired this board in 1990. He was on the Presidential Commission on Space Shuttle Challenger Accident in 1986.

He is a consultant to: Defense Science Board; Hercules Aerospace Corp.; Headquarters NASA; MIT Lincoln Laboratory; and Sverdrup Technology Corporation.

Dr. Covert is the recipient of many awards for technical contributions and public service. They include: Exceptional Civilian Service Award (USAF), 1973 and 1986; University Educator of the Year, 1980; NASA Public Service Award, 1981; MIT Graduate Student Outstanding Teacher Award, 1985; American Institute of Aeronautics and Astronautics Ground Testing Award, 1990; AGARD von Karman Medal, 1990; and American Institute of Aeronautics and Astronautics W.F. Durand Lectureship, 1992.

HAL FLUK

UNITED STATES AIR FORCE: Special Weapons

INDUSTRY: X-19 VSTOL aircraft - responsible for aerodynamic flight load aerodynamic research, powered list control requirements, wind tunnel test planning and analysis, vertical and transition flight analysis, final program report covering design and technology.

Helicopters - stability, autorotational characteristics, near and far field velocities of hovering rotors, aerodynamic planning, Engineering and Computer Department interfaces

GOVERNMENT: SERD catapult studies, R&D planning, Advanced Systems, Aircraft/Ship interfaces and system MOE's.

ERIC LISTER

Mr. Lister received a Master of Science degree in Mechanical Engineering from Drexel University in 1968.

He has 33 years of experience in research, development, test, and evaluation of large aviation gas turbine powerplants, fuels, lubricants, and related technology. He was heavily involved with hardware and analysis, mostly for the U.S. Navy. He was on the staff of the Naval Air Propulsion Test Center for 22 years. There, he was Project Engineer on full-scale engine tests, Project Manager in High Temperature Technology, and Supervisor of Exploratory Development. At the Department of Energy, he developed combustors for alternate fuels. In twelve years with various companies, he supported flight test and engine development on the E-2C aircraft with T56 engines, the V22 aircraft with T406 engines the F/14 with F110 engines, and the E-6A with CFM56 engines. He also did analysis of engine aging, risk of post crash fires, and general risk assessment. He currently supports ARPA on the X-31 research aircraft with a F404 engine.

Mr. Lister has accomplished much in the civil applications of turbine engines. He discovered the cause of engine flameouts in the SA242. He identified engine contributions to 226 US commercial accidents. He identified the potential for CFM56 blade disc dovetail failure. He created a statistical model to predict post crash fires. He answered engine-related questions for the National Transportation Safety Board investigation of major air crash in 1989. He has used computer aided design to identify risk to airplane designs from rotor bursts.

Mr. Lister has made major contributions related to the military applications of turbine engines. For the U.S. Navy he has advance engine technology through design, development, test and evaluation. The Deputy Director of Research and Engineering has called on Mr. Lister for technology assessments. He has solves may problems, beyond the manufacturers capability, that occurred during Navy operation of engines. He contributed directly to the development of seven major turbine engines including solutions for difficult problems, such as water ingestion. Mr. Lister is very knowledgeable of the CFM56 service history and problems. He is currently developing propulsion issues for the Wingship Technical Evaluation Team.

DIETER W. CZIMMEK

Mr. Czimmek is a Research Project Engineer in the R&D Department of the Newport News Shipbuilding Company in Virginia. He received his B.S. degree in Naval Architecture and Marine Engineering in 1956 from a Polytechnical Academy in Germany. He received additional training in Computer Programming from the Fenn College in Cleveland, Ohio, and he took engineering courses in Design of Offshore Platforms at the University of Texas in Austin. He is a life member of SNAME, a member of the SNAME HS-9 Research Panel and a member of ASNE. He is holding two U.S. industrial patents. He is the author of several SNAME papers and of a paper for FAST '91 International Conference.

Mr. Czimmek has a total of 37 years of professional experience in the field of Naval Architecture and Structural Design of which he worked 24 years with Newport News Shipbuilding. Fifteen years of that time he worked in the R&D Department of Newport News Shipbuilding. During that time he was involved in product-oriented research of various ship types which included the design of specialized cargo ships, chemical carriers, icebreakers, icebreaking tankers, icebreaking LNG carriers, offshore drilling platforms, oceanographic research vessels, naval combatants and advanced hull forms with different applications. He also performed various studies for the Maritime Administration, the Ship Structures Committee and NAVSEA. In the areas of advanced hulls, Mr. Czimmek was a project leader for a 3,000-Ton SWATH oceanographic research vessel design and a project leader for a 20,000-Ton Surface Effect Fast Sealift Ship design under a contract with NAVSEA. He also developed inhouse concepts for a 1,500-Ton Surface Effect Ship Navy Escort.

Prior to his time in the R&D department, Mr. Czimmek worked in the Hull Department of Newport News Shipbuilding in a structural engineering and supervisory capacity performing analyses for naval combatants, aircraft carriers, submarines, LNG carriers and other commercial vessels. Before joining Newport News Shipbuilding, Mr. Czimmek worked in Germany for the Blohm & Voss Shipyard and in the U.S. for American Shipbuilding, Bethlehem Steel Sparrows Point and Avondale Shipyards as naval architect and engineering supervisor for a total of thirteen years. In that capacity he performed naval architectural and structural analyses, or supervised such work, for commercial, USCG and U.S. ship contracts.

DANIEL SAVITSKY

Dr. Savitsky is currently Professor Emeritus and Senior Consultant to Davidson Laboratory. He earned his Ph.D degree in Oceanography from New York University in 1972.

Dr. Savitsky was appointed Director of the Davidson Laboratory, Stevens Institute of Technology in 1982 and served in that capacity until 1989. He was also Professor in the Ocean the Ocean Engineering Department of Stevens where he taught graduate courses in the hydrodynamics of seaplane design and high speed marine craft with emphasis on planing hull forms. For nine years, he was Chairman of the High Speed Marine Vehicle Committee of the International Towing Tank conference. He was the advocate of planing hulls in the Advanced Naval Vehicle Concept Evaluation, which also considered Wingships. He is active on committees of the Society of Naval Architects and Marine Engineers. He has prepared several papers on the state of the art of seaplane hulls and planing hulls. He has published over 80 technical papers related to high speed marine vehicles. He has served on Naval Studies Board of the National Academy of Sciences to define the role of Small Waterplane Area Twin Hull (SWATH) ships, to define the applications of advanced technologies in the design of future aircraft carriers, and to study mine countermeasures.

Earlier, he was at the Langly Laboratory of the former National Advisory Committee for Aeronautics (now NASA) where he did basic research of water-based aircraft, hydroskis, and planing craft. He also designed seaplane hulls and float-type landing gear for water-based aircraft.

Dr. Savitsky is a Registered Professional Engineer in the State of New York. He is a member of the academic honorary society, Sigma Xi. He belongs to the Society of Naval Architects and Marine Engineers and the American Society of Naval Engineers.

C.F. SNYDER III

Mr. Snyder received a Bachelor's degree in Control Systems Engineering from the U.S. Naval Academy and a Master's degree from Michigan State University in the field of Electrical Engineering. He served at sea in Destroyers prior to being selected for Engineering Duty.

Mr. Snyder's first tour as an ED, at the Center for Naval Analyses, saw him performing Operations Analysis on a range of issues; Ship Maintenance Resource Allocation, the Navy's overall maintenance philosophy and infrastructure, Overseas homeporting of Navy ships, Aircraft Carrier Airwing spare parts provisioning, and Advanced Aircraft Carrier Conceptual Design.

At the Naval Sea Systems Command, he served as the Combat Systems Manager for the California class of Nuclear powered cruisers. Subsequent tours included Ship Superintendent for Nuclear powered submarine overhauls and re-fit periods at advanced bases; Maintenance Officer for Destroyers, Cruisers, and Battleships at the Atlantic Fleet Headquarters; and Budget and Planning Officer for all Atlantic Fleet Surface Ships.

Mr. Snyder was the Nimitz class aircraft carrier Project Officer at Newport News, Virginia, where he was in charge of contract administration for carrier construction. During his tours, USS CARL VINSON, USS THEODORE ROOSEVELT, and USS ABRAHAM LINCOLN were delivered to the fleet.

After retiring from active duty, Mr. Snyder joined the Naval Surface Warfare Center, where he is assigned to the Systems Assessment and Engineering Department. He managed the operations analysis portion of the Fast Sealift Ship Technology Development Program. He is the Center's coordinator of future Naval Force Architecture Development efforts, develops cost estimates for current and future systems, and is contributing to a study of Product Oriented Design and Construction methods and their applicability to Navy ships.

Wingship Investigation

Mission Application Studies

CONTENTS

Appendix J

Lockheed
Aeronautical Systems Company

A Division of Lockheed Corporation
Marietta, Georgia 30063

L94R0294
25 April 1994

Subject: Contract F33657-90-D-0028, Task Order 0014, Wing-In-Ground Effect Support Analysis, Transmittal of Final Report CDRL 0004

To: USAF/AFMC
Aeronautical Systems Center (ASC)
Wright-Patterson AFB, OH 45433-7238
Attn: ASC/XRED (R. Johnson)

Reference: (A) CDRL Seq. No. 0004 (Technical Reports - Final Report) of the subject contract

Enclosure: (a) Two (2) copies of Final Report "Wing-In-Ground Effect (WIG) Support Analysis Study", LG94ER0059, dated March 1994

1. In accordance with the reference (A) requirements, enclosure (a) is submitted for the Air Force's information and use. It should be noted that a draft copy of this report was submitted to the Air Force (R. Janssen) and NSWC Carderock (C. F. Snyder) at the 15 March review at NSWC.

2. If you have any questions concerning this submittal, please contact Michael Wolter at (404) 494-0199 or the undersigned at (404) 494-1014.

LOCKHEED AERONAUTICAL SYSTEMS COMPANY

G. R. Goddard
G. R. Goddard
Configuration and Data Manager

GRG:MWW:rah

cc: ASC/XREC [w/2 cy encl (a)]
ASC/XRP

(continued on Page 2)

CDNSWC [3 cy encl (a)]
Code 211
Bethesda, MD 20084-5000
Attn: C. F. Snyder

WL/FIGC

Advanced Research Projects Agency
3701 N. Fairfax Drive
Arlington, VA 22203-1714
Attn: ASTO

(all w/cy encl)

WING-IN-GROUND EFFECT (WIG) SUPPORT ANALYSIS STUDY

Report Number LG94ER0059

March 1994

Prepared under U.S. Air Force ASC/PKGA
Contract F33657-90-D-0028, Order 0014
to support
The Naval Surface Warfare Center's
Assessment of the Operational Utility of WIG Concepts

Lockheed Aeronautical Systems Company

A DIVISION OF THE LOCKHEED CORPORATION

Marietta, Georgia 30063

FOREWORD

The WIG Support Analysis Study, reported herein, was performed by the Lockheed Aeronautical Systems Company for the Naval Surface Warfare Center's Assessment of the Operational Utility of Wing-in-Ground Effect (WIG) Concepts under the direction of Mr. C. F. Snyder. The Lockheed effort was administered under U. S. Air Force ASC/PKGA contract F33657-90-D-0028, Order 0014, with technical oversight provided by Mr. Randy Janssen. The duration of Lockheed's effort extended from January 11, 1994 to March 31, 1994.

Lockheed personnel who contributed to this effort and their areas of responsibility are:

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Clifford L. Robinson	Cost Analysis
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Anthony J. Scibilia	Loadability, Closure, and Wargaming Effectiveness

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1.0 INTRODUCTION AND SUMMARY

In early 1993, Congress mandated that the Advanced Research Project Agency lead an evaluation of the technical feasibility and potential applications of the Wing-in-Ground effect (WIG) concept, also known as a Wingship. Figure 1.0-1 is an artist's concept of one Wingship design that Aerocon Incorporated created and designated the DASH 1.6 5000-ton WIG. The Russian Orlyonuk is a much smaller wingship concept that has been operated for a number of years.

ARPA convened a Wingship Technical Evaluation Team composed of government and industry scientists and engineers in the Summer of 1993 to study the technical feasibility of the WIG concept. The Team concluded that technology breakthroughs are not required to design, develop, and demonstrate the WIG concept. The Team predicted that major efforts will be required to develop the engines, ground-effect lift technology, and vehicle of the large scale proposed for the AEROCON concept.

Based on the Wingship Technical Evaluation Team's findings that a large-size WIG is technically feasible, ARPA commissioned the Naval Surface Warfare Center (NSWC) to assemble a Wingship Mission Analysis Team to conduct an assessment of the operational utility of WIG concepts for military and commercial applications. The NSWC contracted with several government agencies and industry participants for assistance in identifying, developing, and evaluating potential uses for WIG vehicles. One of these industry participants is the Lockheed Aeronautical Systems Company.

1.1 OBJECTIVES

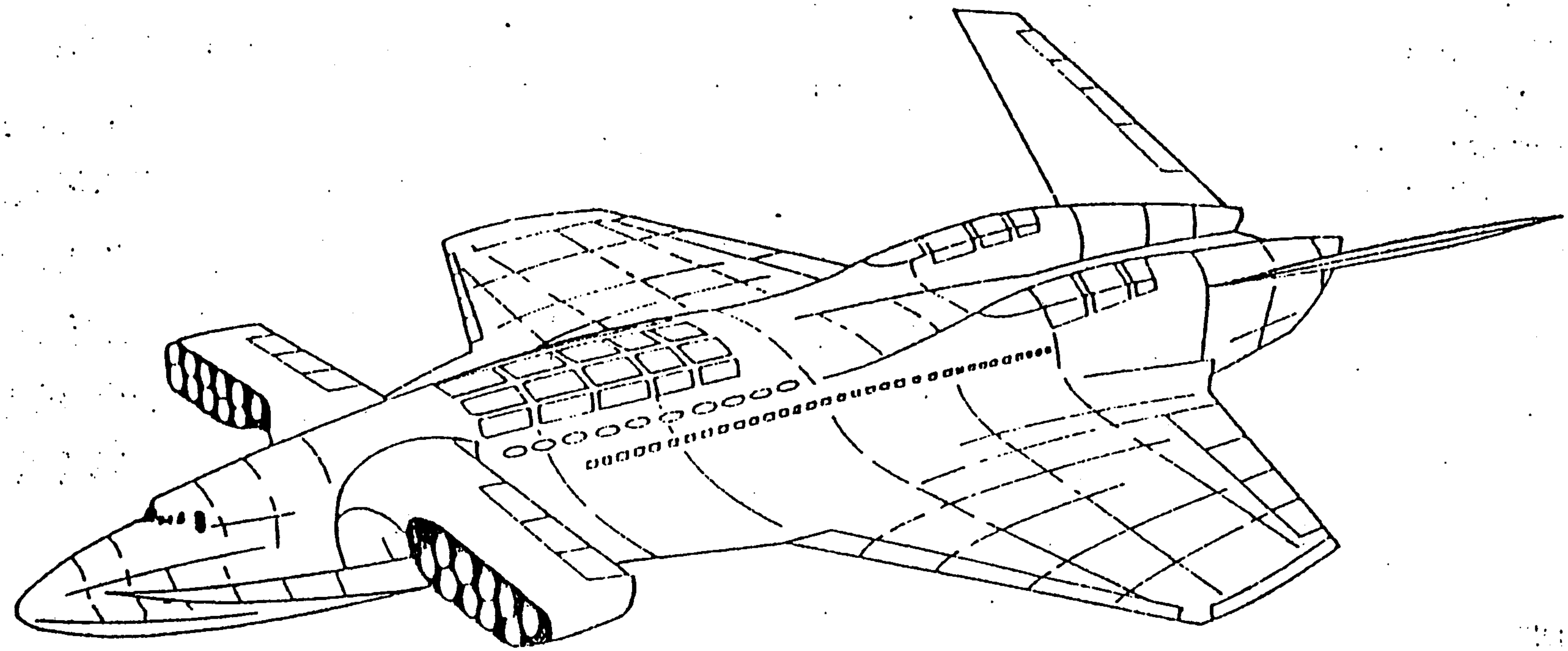
The objectives of Lockheed's analytical support to the NSWC Wingship Mission Analysis Team are:

- Effectiveness evaluations of two WIG concept point designs for performing long-range, heavy lift missions;
- Identification of potential commercial applications; and
- Assessments of the life cycle and mission costs of the two WIG point designs.

1.2 APPROACH

Lockheed's approach for evaluating WIG effectiveness entails a variation of the DoD Mobility Requirements Study's (MRS) Southwest Asia (SWA) major regional contingency (Reference 1). Figure 1.2-1 from the MRS shows the required delivery schedule for the tonnage of the military units and supplies needed during a simulated 14-week conflict to stop a hostile force's advance into Saudi Arabia and ultimately defeat it within a moderate warfighting risk level time period. This figure also shows that there is a shortfall between required deliveries and those projected with the air and sea mobility assets, listed in Figure 1.2-2, that are

AEROCON WINGSHIP CONCEPT



Line drawing of Aerocon's concept for a wingship of 5,000 tons gross weight.

Figure 1.0-1. Aerocon Wingship Concept

MRS SHOWS 1999 BASELINE ASSETS INADEQUATE TO MEET SWA MEDIUM RISK CLOSURE REQUIREMENTS

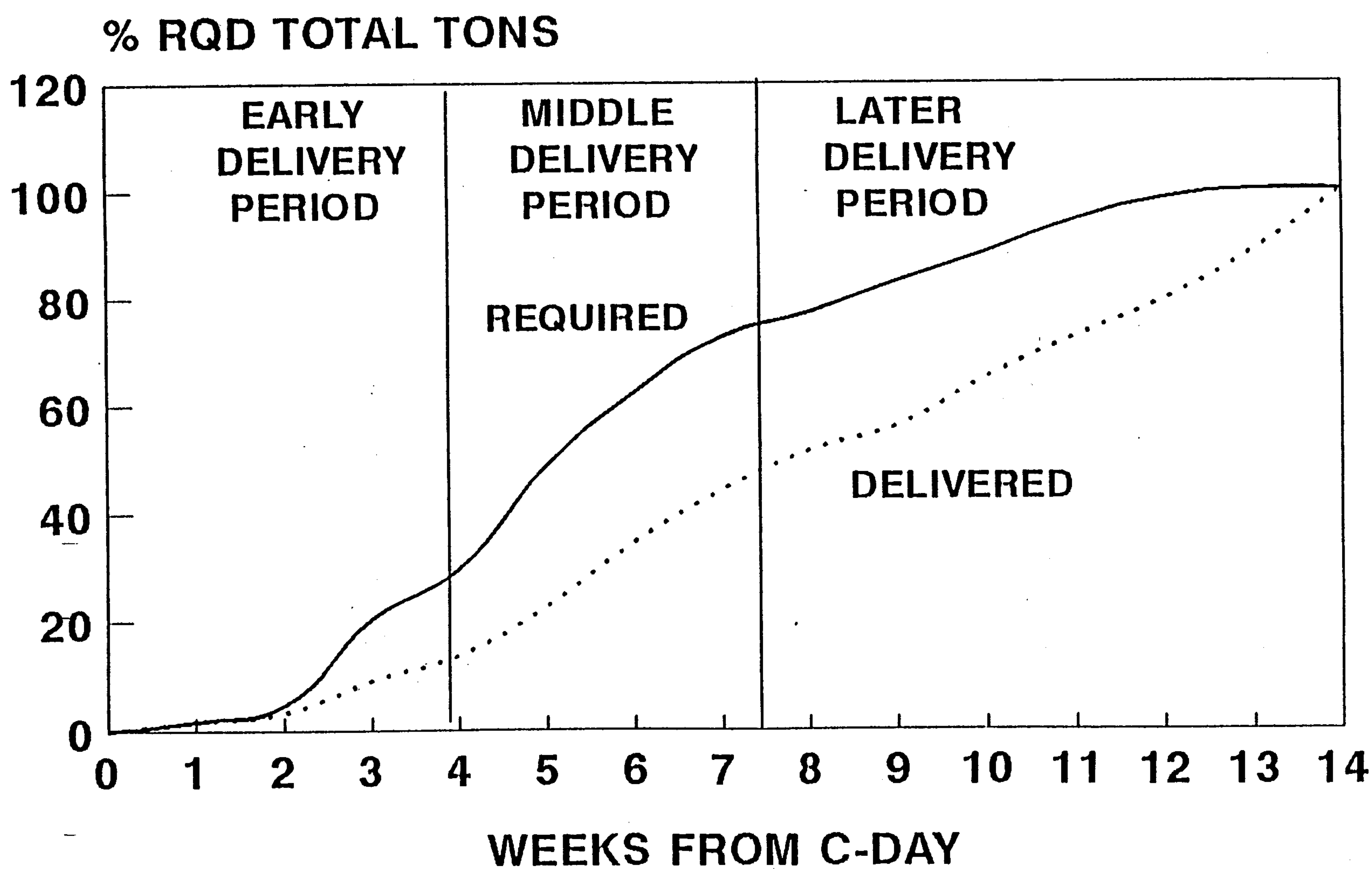


Figure 1.2-1. MRS Shows 1999 Baseline Assets Inadequate to Meet SWA Medium Risk Closure Requirements

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MRS MOBILITY ASSETS

FLEET CONFIDENCE	1999 BASE LOW	ADD-ON MEDIUM	ADD-ON HIGH
o SEALIFT*			
- READY RESERVE FORCE**	104		
- MILITARY SEA COMMAND***	19	22	32
- US FLAG	71		
- EFFECTIVE US CONTROL	14		
o AIRLIFT, PAA			
- C-5	109		
- KC-10	57		
- C-141	152		
- C-17	80		
- CRAF I 747 EQV PAX/CARGO	18/23		
- CRAF II 747 EQV PAX/CARGO	73/41	20/0	35/0
o FOREIGN AND ALLIED ASSETS	INCLUDED		

* INCLUDES PRE-POSITION

** $2.7B ADDED TO FYDP

*** INCLUDES 8 FSS

Figure 1.2-2. MRS SWA Mobility Assets

postulated for fiscal year 1999. The MRS points out that delivery of forces during the early period is most critical. While the airlift fleet transports all of the light units that are expected to move within the first two weeks and pre-positioned ships move the equipment of some heavy units to the theater of operations, the shortfall arises because the first sealift ships which carry the heavy Army units do not begin arriving from the Continental United States (CONUS) until 27 days after C-day (the day when units commence movement from their CONUS bases to the combat theater). Some method of transportation is desired that can deliver heavy Army units usually carried by ships but at speeds generally associated with aircraft. This study investigates the potential of WIGs to be the desired unique mode of transportation.

The approach for this WIG effectiveness evaluation is to determine fleet sizes that are required for each of the two WIG designs to deliver two U.S. Army heavy mechanized divisions from the CONUS to SWA. Acceptable WIG fleet sizes are those which deliver the two divisions quicker than if they are transported by sealift. Benefits of earlier delivery of the two divisions are quantified through campaign analyses which measure reductions in enemy penetrations.

The approach for identifying potential commercial applications is to conduct brainstorming sessions with senior technical personnel having extensive experience in transportation.

Lockheed's life cycle cost model is used for estimating the acquisition and peacetime operating and support costs for the two WIG concepts.

1.3 SUMMARY OF RESULTS

Only minimal conceptual-level design, performance, and operational data are available for the two WIG point designs evaluated. Data that are available, particularly for weights, are not uniformly consistent. Further, many assumptions were made based on engineering judgment and experience to create data needed to perform this study. These data inconsistencies and/or assumptions are responsible for the trends of some of the study results and merit further investigation.

Major findings of this study are summarized in Figure 1.3-1. To carry two U.S. Army heavy mechanized divisions with a total weight of 192,190 tons requires 64 loads with the 5000-ton WIG and 185 loads with the 3000-ton WIG. For comparison, movement of these two divisions by more conventional mobility assets require either 12 loads on 40,000-ton large medium-speed roll-on/roll-off ships (LMSRs), or 1568 loads on 131-ton payload C-5s.

To complete delivery of the two divisions in equal time periods requires a fleet of 3000-ton WIGs that is about 3.5 times the fleet of 5000-ton WIGs. The major reasons the fleet sizes are not in direct proportion to vehicle size are the differences in block speeds and in payload-to-gross-weight fractions. The developers provided single invariant block speeds, regardless of range, of 400 and 308 knots for the 5000-ton and 3000-ton WIGs,

SUMMARY OF RESULTS

WIG CONCEPT	AEROCON 5000-TON	AIR FORCE 3000-TON
NUMBER OF LOADS PER DIVISION	64	185
PAA FLEET SIZES FOR		
CLOSURE TIMES OF		
- 27 DAYS	16	56
- 21.5 DAYS	20	74
- 18 DAYS	26	90
COSTS, M$		
UNIT ACQUISITION	2,819	1,577.6
21.5 DAY CLOSURE		
- FLEET ACQUISITION	170,700	232,300
- FLEET LCC	192,200	285,600
UNIT COST/PAYLOAD TON	1.6	2.6

Figure 1.3-1. [Su]mmary of Results

state-

respectively. Indicative of much different structural design approaches, the payload-to-gross-weight fractions are 0.345 for the 5000-ton design and a much poorer 0.2 for the 3000-ton design.

If the fleets are sized to meet a 21.5-day closure time, the acquisition costs for the 3000-ton WIG are about twice the cost for the 5000-ton WIG. The corresponding life cycle costs are about 50 percent higher for the 3000-ton WIG.

In comparison, the unit acquisition cost of a new LMSR ship is about 240 million dollars. A fleet of 12 ships, at a total cost of 2.88 billion dollars, can deliver both divisions from CONUS to the theater but they take 27 days, which is somewhat longer than with WIGs. Late arrival in theater by the divisions produces substantial warfighting risk and higher penalties in lost time and lives and in additional costs due to the extended wartime effort to restore the borders.

Figure 1.3-2 summarizes the conclusions and recommendations of this study. WIGs have the potential to carry large quantities of heavy cargo, which are currently relegated to ships, at aircraft speeds to make deliveries when time is critical. On a flyaway cost per ton of cargo carrying capability, WIGs are competitive with C-5 airlift but are substantially higher than LMSR ships. The WIG concept has several potential commercial applications, but in much smaller vehicles than the two point designs.

This study makes two general recommendations. First, extend the existing design efforts to address numerous operational details that have not been considered so far, such as loading of the 3000-ton concept, and to gain consistency and credibility for the predicted weight, performance, and cost data. Second, conduct analysis of military and commercial needs and derive design requirements for WIG vehicles. The derived requirements will probably be quite different from those used on the two point designs evaluated in this study.

SUMMARY
CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS

- WIGS HAVE UNIQUE POTENTIAL TO CARRY HEAVY CARGO RELEGATED TO SHIPS AT AIRCRAFT SPEEDS WHEN TIME IS CRITICAL
- WIGS COST/TON
  - COMPETITIVE WITH AIRLIFT
  - SUBSTANTIALLY HIGHER THAN SEALIFT
- WIG CONCEPT HAS POTENTIAL COMMERCIAL APPLICATIONS BUT IN SMALLER VEHICLE THAN TWO POINT DESIGNS

RECOMMENDATIONS

- EXTEND EXISTING DESIGN EFFORTS
  - ADDRESS OPERATIONAL DETAILS
  - GAIN WEIGHT, PERFORMANCE, & COST CREDIBILITY
- DERIVE MILITARY/COMMERCIAL DESIGN REQUIREMENTS

Figure 1.3-2. Summary of Conclusions and Recommendations

2.0 DESCRIPTION OF WIG CONCEPTS

The two WIG concepts evaluated in this study are the DASH-1.6, 5000-ton Wingship created by Aerocon Incorporated, and a 3000-ton variant developed by the Air Force ASC/XREDT of a Northrop 800-ton concept. Details on these two concepts, as provided by their developers (References 2 and 3), are presented below.

2.1 DIMENSIONS AND DRAWINGS (From References 2 and 3)

Three-view drawings are presented in Figures 2.1-1 and 2.1-2 for the Aerocon and Northrop WIG concepts. Figures 2.1-3 and 2.1-4 are inboard profile drawings that show the cargo compartment areas for the two concepts. Note that both concepts employ upper and lower decks to carry vehicles and palletized/containerized cargo.

The Aerocon concept has two main decks (A1 lower and C1 upper) for carrying vehicles and equipment. Heavier equipment, such as tanks, is restricted to the lower deck. Personnel can be carried on the forward and aft B deck as well as the amidship D and E decks that are not shown. The Air Force concept does not have a separate passenger compartment; passengers are seated along the sides of the cargo compartment in the same way they are in existing military transport aircraft.

General dimensions for the two concepts are:

Dimension	Aerocon 5000 ton	Air Force 3000 ton
Overall Length, ft	566	452.5
Wing Span, ft	340	100
Tail Height, ft	88	71
Upper Compartment LxWxH, ft	311x39x13.5	196.5x28.4x14
Lower Compartment LxWxH, ft	316x72x19.5	226.25x28.4x19

2.2 WEIGHT STATEMENTS (From References 2 and 3)

The two concept developers provided the weight breakdowns tabulated in Figure 2.2-1. It is evident that different terminology and design approaches are being used. The short time period allotted for this study did not permit an investigation of the basis for the differences. These values were used as provided without question.

2.3 LOADING/UNLOADING APPROACH

2.3.1 Aerocon 5000-ton Wingship (From References 2 and 4)

Figure 2.3-1 from Aerocon, Inc. shows the two main cargo decks as well as the access doors and ramps for the 5000-ton concept. There are two forward and two rear ramps inside the WIG fuselage that provide access to the upper deck. All four of these ramps may

AEROCON DASH-1.6 WINGSHIP 3-VIEW DRAWING

DIMENSIONS IN FEET

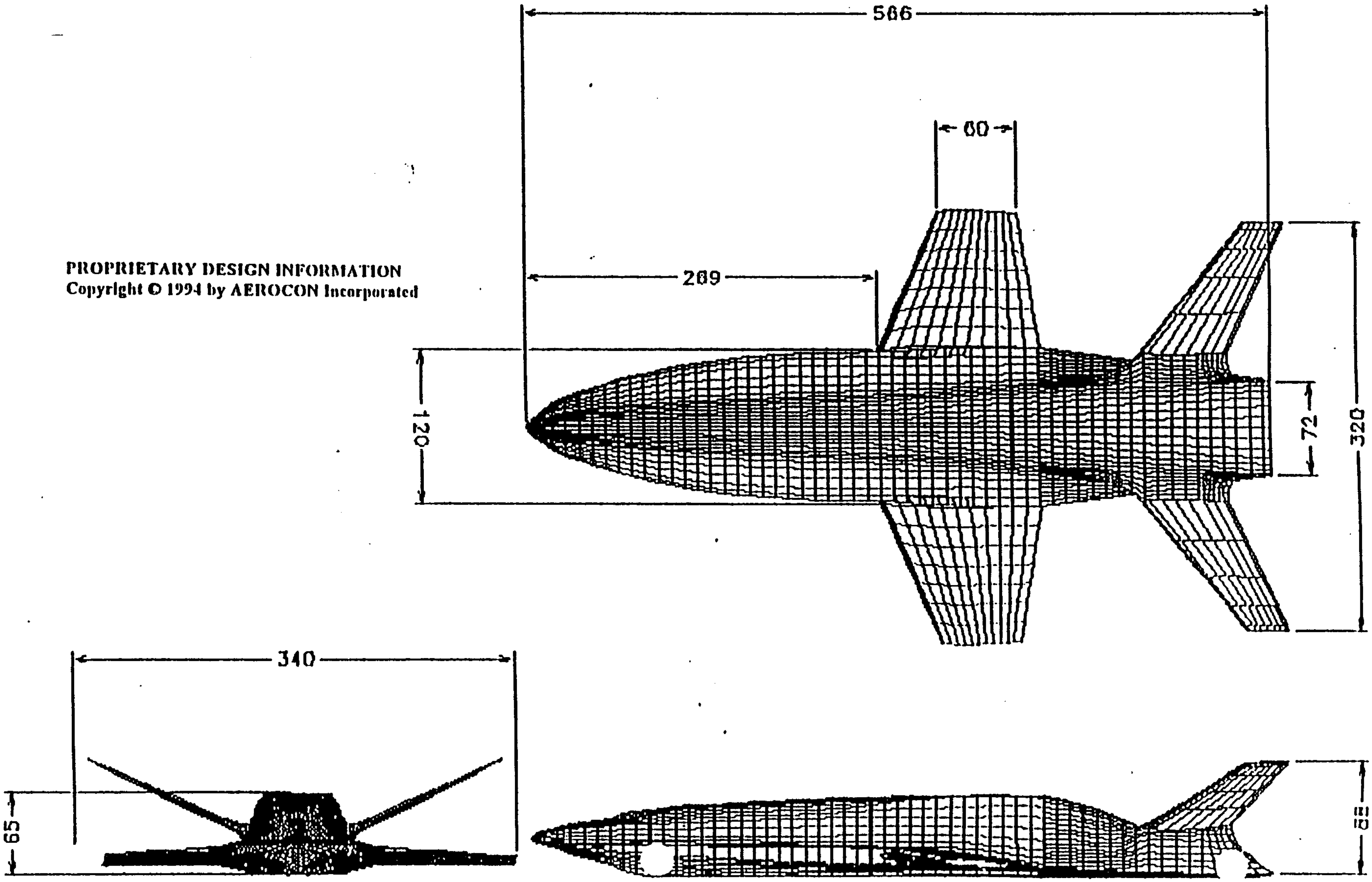


Figure 2.1-1. Aerocon DASH-1.6 Wingship 3-View Drawing

AIR FORCE 3000-TON WIG 3-VIEW DRAWING
DIMENSIONS IN FEET

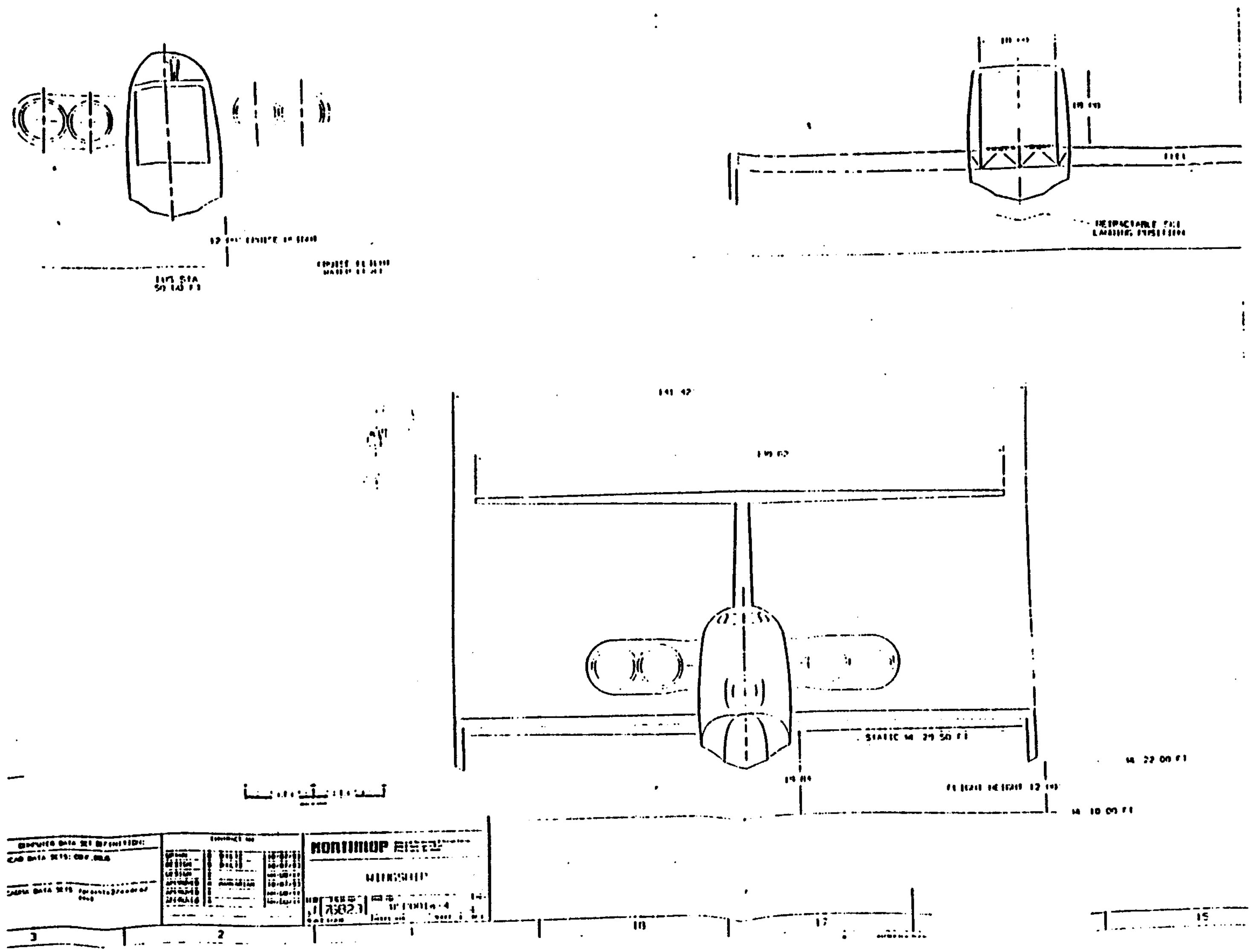


Figure 2.1-2. Air Force 3000-Ton WIG 3-View Drawing

AEROCON WINGSHIP INBOARD PROFILES

DIMENSIONS IN FEET

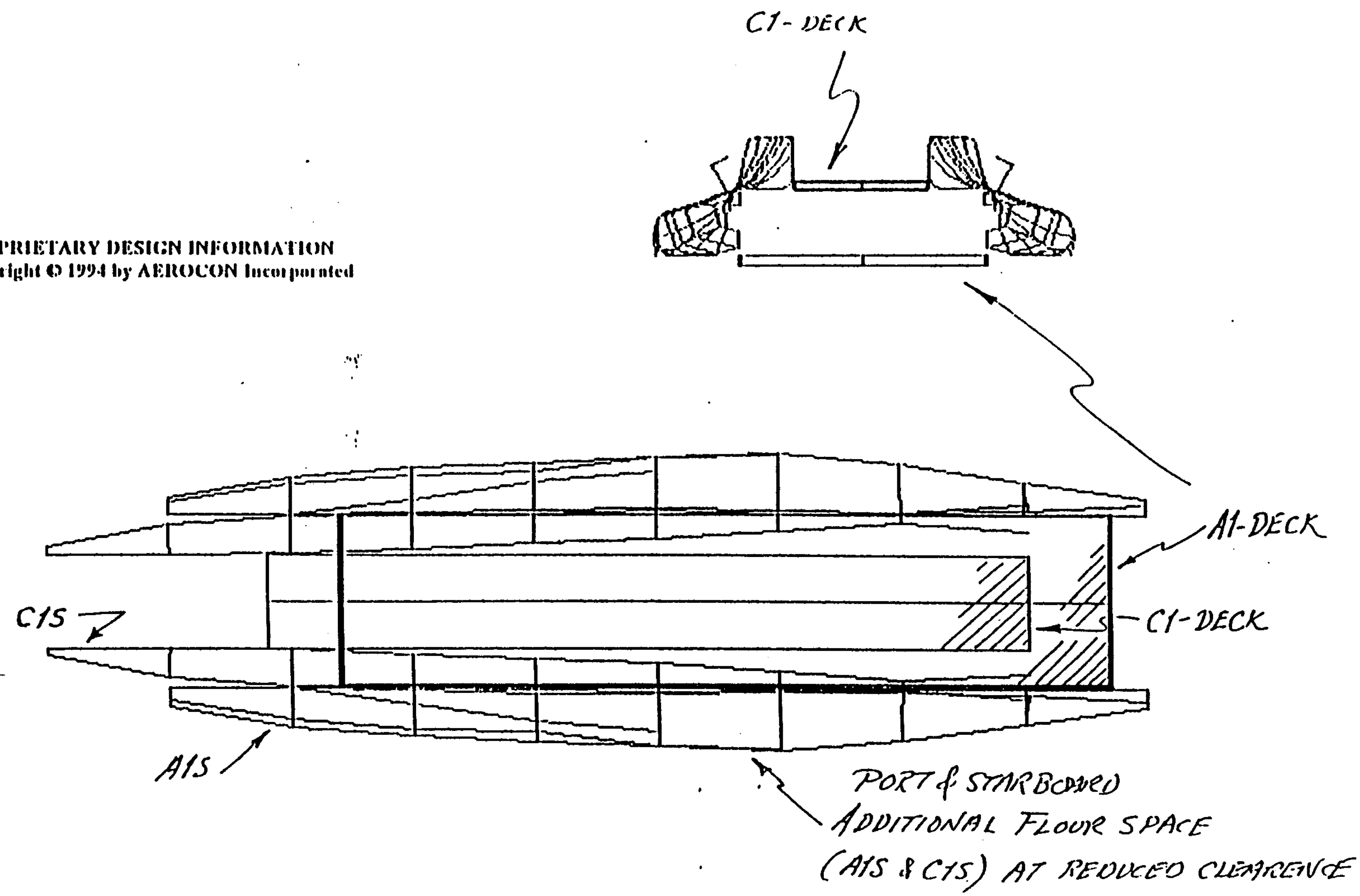


Figure 2.1-3. Aerocon Wingship Inboard Profiles

AIR FORCE 3000-TON WIG INBOARD PROFILES

DIMENSIONS IN FEET

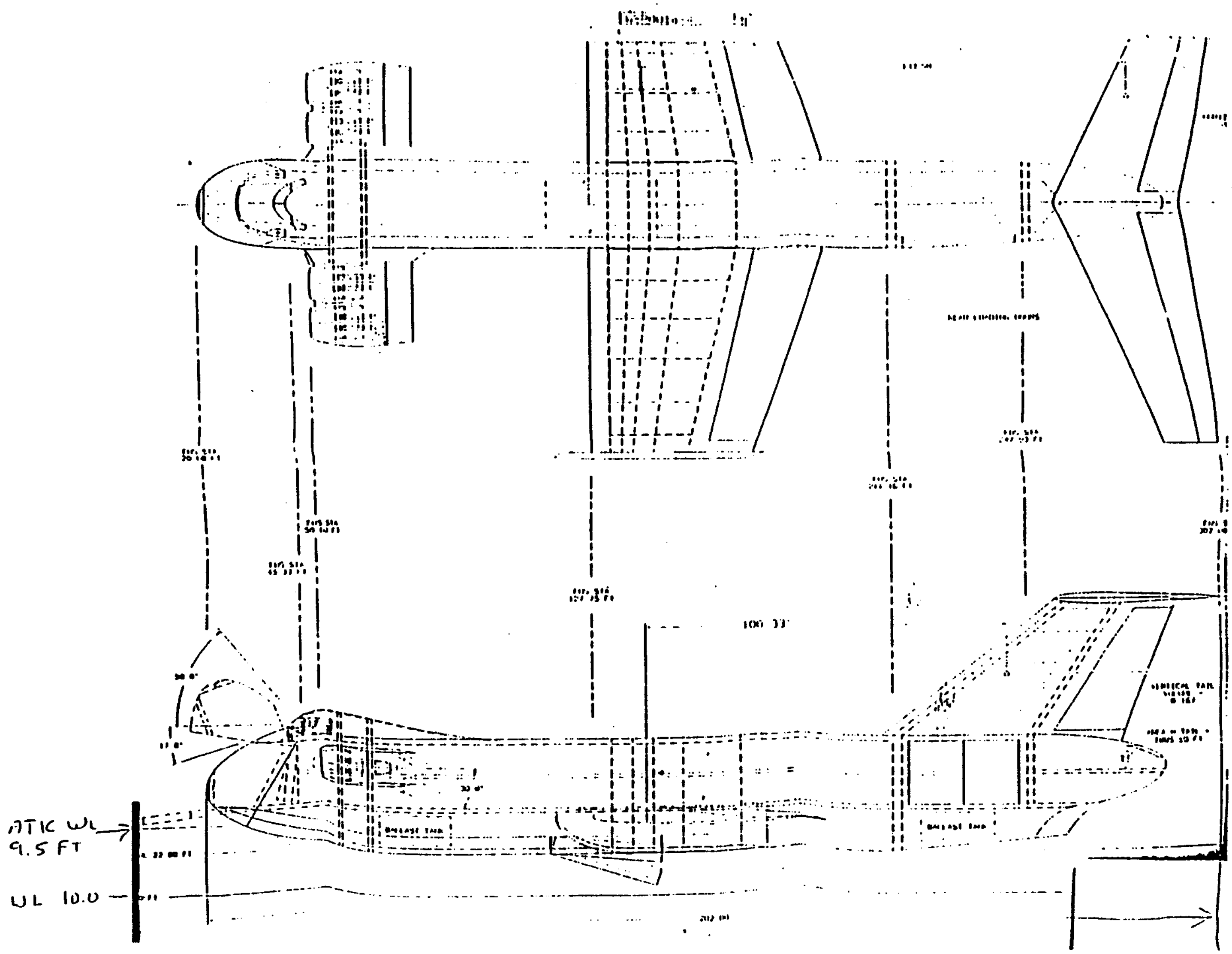


Figure 2.1-4. Air Force 3000-Ton WIG Inboard Profiles

WEIGHT STATEMENT FOR WIG DESIGNS

WEIGHTS IN POUNDS

Item	Aerocon 5000 ton	Air Force 3000 ton
Structure		
Fuselage	821,976	1,019,530
Wing	616,926	517,516
Empennage	360,870	178,521
Landing Gear Ski		117,149
Engine Bridge, Nacelle	217,475	196,305
Propulsion	262,533	303,493
Fixed Equipment		
Flight Controls	57,690	38,125
Hydraulics	60,600	32,801
Electrical	56,380	22,979
Avionics	22,450	7,035
Furnishings	388,275	39,185
Air Conditioning	20,700	6,109
Load & Handling		2,400
Anti-Ice		2,020
Aux Power		1,600
Harbor Group	103,430	
Fuel System	297,100	213,195
Emergency Equipment	88,760	
Weight Empty	3,286,405	2,697,971
Operating Item Weights	213,600	23,687
Operating Empty Weight	3,500,005	2,721,659
Payload	3,445,000	1,200,000
Fuel	3,052,400	2,078,341
Takeoff Gross Weight	10,001,905	6,000,000

Figure 2.2-1. Weight Statements for WIG Designs

AEROCON CARGO DECK LOADING/UNLOADING

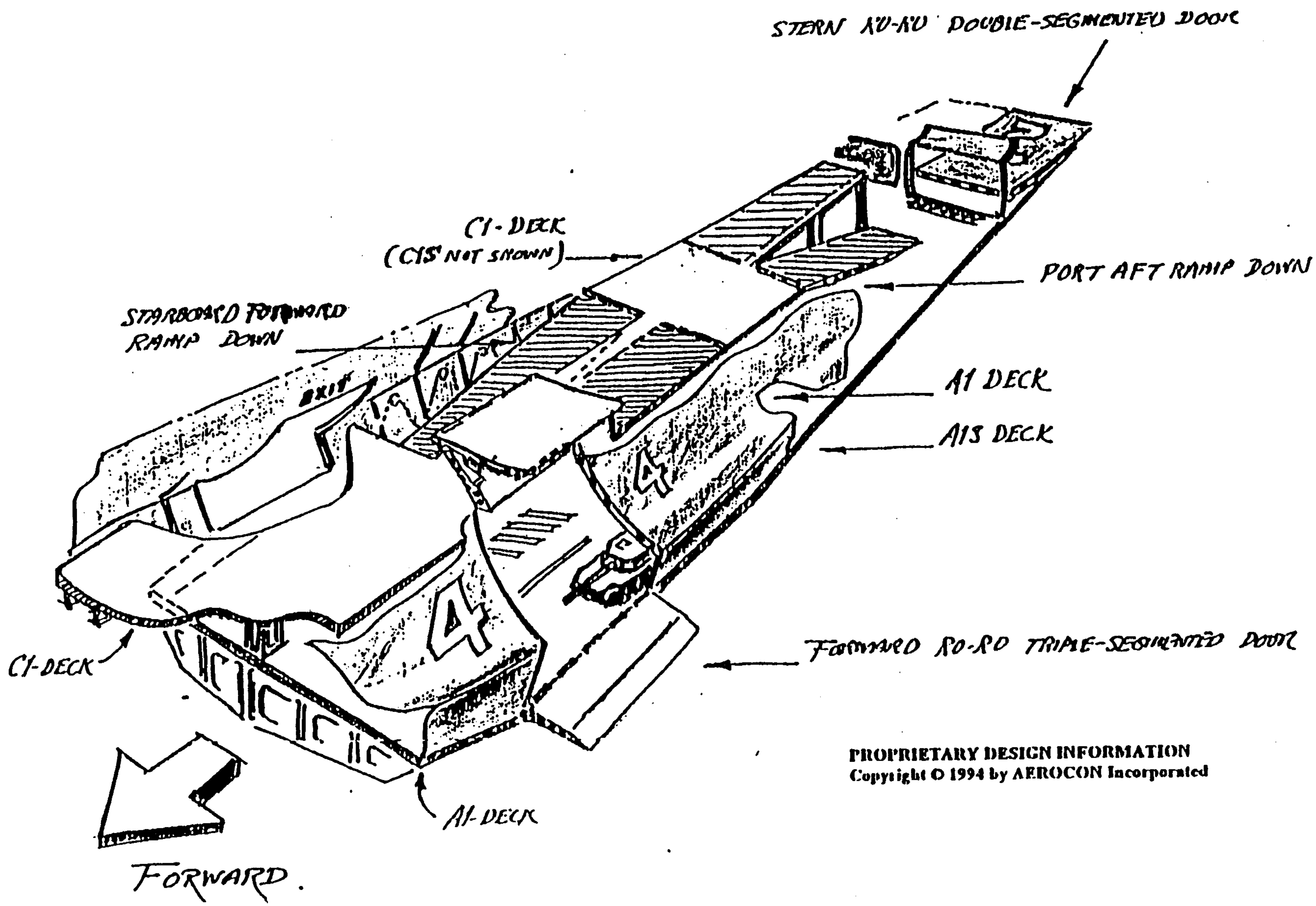


Figure 2.3-1. Aerocon Cargo Deck Loading/Unloading

state-

be lifted while loaded to a position level with the upper deck to permit full loading of the lower deck. Each of the two forward ramps is 25 ft wide and 135 ft long. The two rear ramps are tapered in width from 28 ft to 31 ft at the hinge location. When used for loading, the rear ramps are sloped at about a 10 percent grade. Essentially flat ramps at the rear and side door locations are required for cargo movement between the lower deck and either port facilities or a beach. These lower deck ramps have not been designed.

Left and right rear cargo compartment doors are 31 ft wide and 19.5 ft high. Left and right forward side cargo compartment doors are 25 ft wide and 19.5 ft high.

Floor strength of the upper deck is less than the lower deck's. Aerocon recommends that the upper deck be restricted to lighter vehicles such as light helicopters, high mobility multi-purpose wheeled vehicles (HMMWV), and small trucks and trailers. Tanks and other heavy vehicles are carried only on the lower deck.

The loading approach suggested by Aerocon (Reference 4) is to drive on through the rear doors. With the forward ramps in a position level with the upper deck, the forward ramps and fixed portion of the upper deck are loaded first. Then, the two rear ramps are loaded and hoisted into a horizontal position. With the rear ramps raised, the lower deck is loaded from front to rear.

For unloading, Aerocon suggested exiting via the front side doors to permit forward drive-off when existing port facilities are available. The sequence of events is to unload the lower deck, to lower the forward ramps from the upper deck, and to unload all cargo on the upper deck.

If port facilities are unavailable for unloading from the forward doors or a beachhead landing is required, unloading would be through the rear doors. To preclude backing vehicles off through the rear doors at the destination, they would be loaded through the front side doors at the CONUS port of embarkation.

2.3.2 Air Force 3000-ton Variant of Northrop WIG (Reference 3)

The inboard profile drawing, shown earlier in Figure 2.1-4, for the Northrop 800-ton WIG depicts a nose visor door and rear port side doors for loading and unloading. No dimensions are given for these doors. It is assumed that the nose visor door will open completely to provide straight-in loading/unloading access to the full 28.4 ft wide and total 33+ ft high (14 ft upper, 19 ft lower, plus upper floor thickness) cargo compartment. The two rear loading doors appear to give full height access; the total width of the two doors appears to be about 60-percent greater than the height.

No ramps or other equipment are shown in the drawings for loading and unloading. Integral ramps, similar to those on the Aerocon concept, could be developed as a future design refinement.

2.4 PERFORMANCE CAPABILITIES

2.4.1 Aerocon 5000-ton Wingship (From Reference 2)

Aerocon derived the payload-range curve in Figure 2.4-1 by using the Brequet range equation and the following design performance parameters:

o Takeoff Gross Weight, W_o	5000 tons
o Empty Weight, $W_E = 0.3588\ W_o$	1794 tons
o Max Fuel, $W_{Fmax} = 0.52\ W_o$	2600 tons
o Max Payload, $W_{Pmax} = 0.345\ W_o$	1725 tons
o Max Payload at W_{Fmax}	606 tons
o Cruise Velocity, V_C	400 knots
o Cruise Altitude, H_C	12 feet
o Cruise L/D	32.5
o Cruise Thrust Specific Fuel Consumption	0.55
o Reserve Alternate Field Distance	350 nm
o Additional Reserve Allowance	5 percent

The block flight time (T_{BL}) for missions carrying at least 606 tons of payload over a range (R) is given by the equation:

$$T_{BL} = R/400 + 3 \text{ hours}$$

With lighter payloads or on return flights, the block flight time is :

$$T_{BL} = R/370 + 3 \text{ hours}$$

Refueling is accomplished via four fuel lines, each seven inches in diameter. All four lines are connected at the tip of one wing; either wing tip can be used. Each line delivers 585 tons of fuel per hour. The time to refuel (T_{RF}) is estimated to be:

$$T_{RF} = W_F/2340 + 0.5 \text{ hours}$$

where W_F is the weight of fuel added.

For overland flight distances (R_o), the degradation in range R_d for payload-range performance is given by

$$R_d = 1.36\ R_o + 165 \text{ nm}$$

This degradation is for overflight at an altitude of 6000 feet and an air speed of 400 knots.

2.4.2 Air Force 3000-ton Variant of Northrop WIG (Reference 3)

The Air Force provided the payload-range curve shown in Figure 2.4-2 for the 3000-ton WIG, and a single invariant block speed value of 308 knots. No other performance data have been provided.

AEROCON WINGSHIP PAYLOAD-RANGE PERFORMANCE

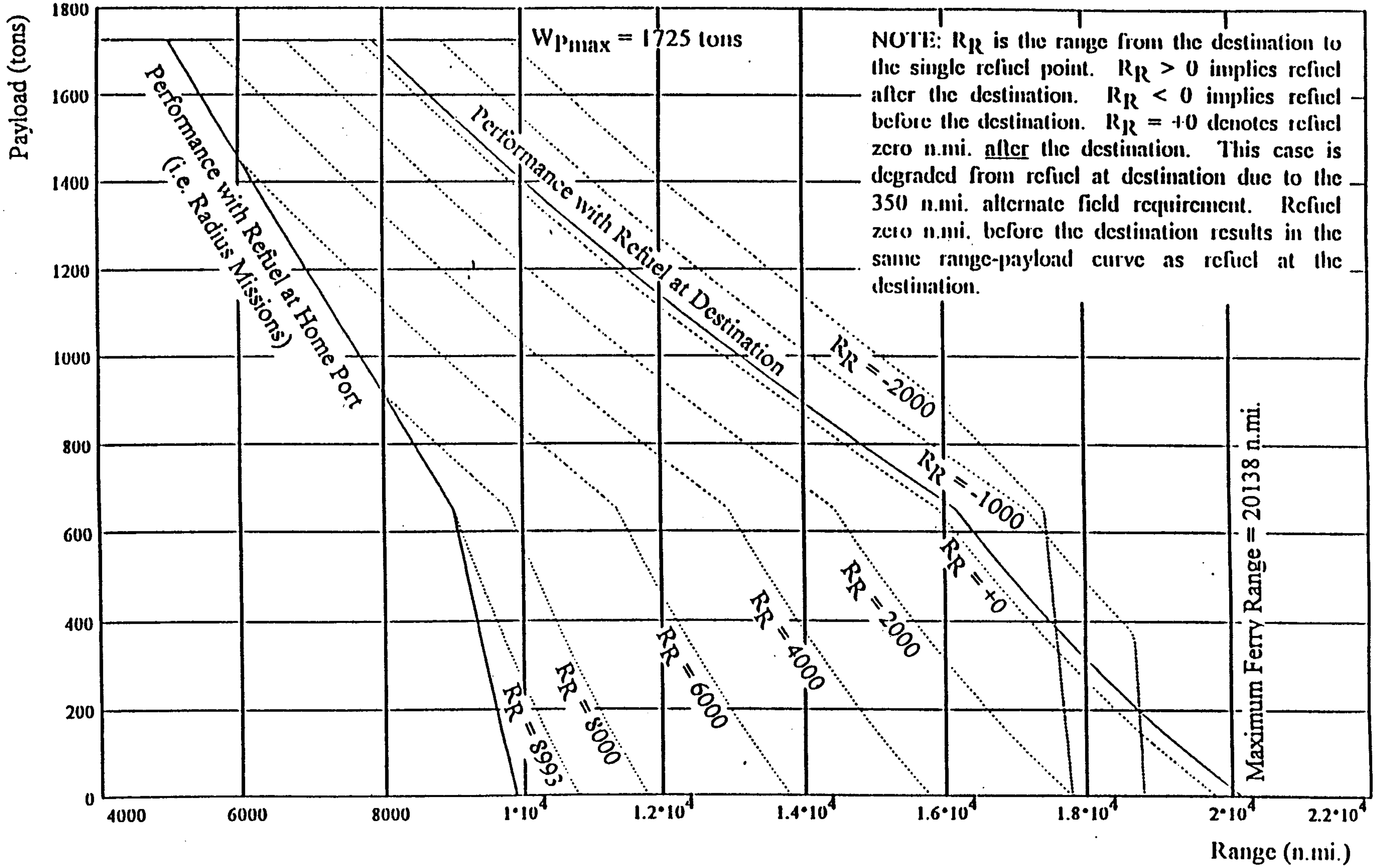


Figure 2.4-1. Aerocon Wingship Payload-Range Performance

AIR FORCE PAYLOAD-RANGE PERFORMANCE

(0.2 PAYLOAD FRACTION)

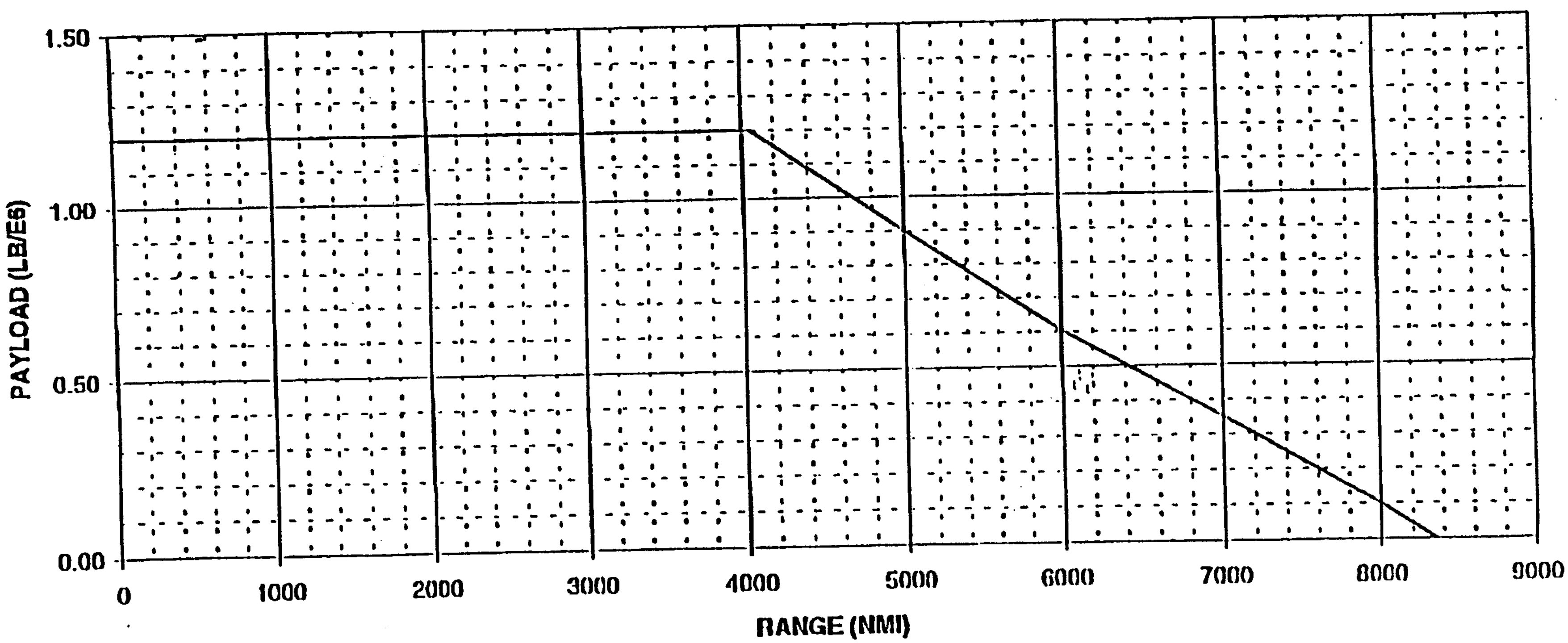


Figure 2.4-2. Air Force 3000-Ton WIG Payload-Range Performance

3.0 EFFECTIVENESS EVALUATION

Effectiveness of the two WIG concepts is measured by the length of time it takes various fleet sizes of each concept to move two U.S. Army heavy divisions from CONUS to SWA. Acceptable fleet sizes are those which deliver the two divisions quicker than if they are transported by ship. For this evaluation, the number of loads is determined for each WIG to carry each division. Next, the travel time is calculated for delivering one load over the mission route to the destination, taking into account loading, unloading, refueling, and transit time. The time to close (deliver) an entire Army division is a function of the total number of loads required by the division and the round-trip travel time by the WIGs. This closure time accounts for the time to move the division from its beddown location to the seaport of embarkation (SPOE) and the staggered delivery sequence by the WIG fleet that fits within load and unloading facility constraints. The closure time of each division is a key factor in determining its wargaming effectiveness benefits achieved through earlier delivery in theater by the WIGs. Details on the effectiveness evaluation are presented next.

3.1 WARGAME SCENARIO DESCRIPTION

The scenario used to assess the benefits of the WIG's lift capabilities involves the outbreak of hostilities in Southwest Asia (SWA). Figure 3.1-1 lists key elements of the Reference 1 Mobility Requirements Study (MRS) rational for selecting the SWA scenario as the most demanding case for analysis of mobility systems. This scenario does not differ drastically from the Desert Shield/Desert Storm conflict.

Our SWA scenario is similar to that of the MRS. Iraq invades Kuwait with the ultimate objective of gaining control of Saudi Arabia and the Persian Gulf. A coalition force consisting of a number of free world nations is formed to stop Iraq's advancement into the Saudi peninsula and restore national geographic borders to their pre-hostilities positions. Figure 3.1-2 lists scenario highlights.

The U.S. provides combat forces and the overall Coalition Force Commander. The scenario begins with intelligence sources reporting the build-up of Iraqi forces near Kuwait's borders. Based upon this intelligence and the request for assistance by the Gulf States, the U.S. President orders the deployment of some U.S. forces to SWA. Deployment begins at C-Day (the date from which movement time is calculated). U.S. Air Force Fighter Squadron Equivalents (FSE), a U.S. Airborne Division, a Patriot Battalion, Special Forces elements, and some Combat Service Support elements are deployed to Saudi by strategic airlift.

The equipment of two Army heavy mechanized brigades and a Marine Expeditionary Brigade (MEB)/Marine Expeditionary Unit (MEU) has been loaded on afloat pre-positioned ships berthed at Diego

GENERAL MRS REASONING

- TWO SIMULTANEOUS MRCs STARTING CONCURRENTLY UNLIKELY

- SWA SCENARIO MOST DEMANDING

- ADEQUATE MOBILITY ASSETS FOR SWA AMPLE FOR OTHER SCENARIOS

- MOBILITY REQUIREMENTS BASED ON MODERATE RISK WARFIGHTING

- MORE IMPORTANT TO REDUCE EARLY RISK THAN LATE RISK

- AFLOAT PRE-POSITIONING AN AFFORDABLE OPTION TO SOLVE EARLY SHORTFALLS

Figure 3.1-1. General MRS Reasoning

SOUTHWEST ASIA SCENARIO EVENTS

- SETTING
  - POST-1999 TIME FRAME
  - SIMILAR TO 1990-91 GULF WAR & DoD MOBILITY REQUIREMENTS STUDY
  - IRAQ CROSSES KUWAIT TO INVADE SAUDI ARABIA AND GAIN CONTROL OF OIL FIELDS AND PERSIAN GULF

- SEQUENCE OF EVENTS
  - IRAQ FORCES MASS ON KUWAIT & SAUDI ARABIA BORDERS
  - U.S. AND OTHER FREE NATIONS PROVIDE FORCES REQUESTED BY GULF STATES
  - COALITION FORMED TO COMBAT INVASION AND RESTORE BOUNDARIES
  - COALITION FORCE DEPLOYMENT BEGINS ON C-DAY PRIOR TO INVASION
  - COALITION FORCES OCCUPY DEFENSIVE POSITIONS ON SAUDI-KUWAIT AND SAUDI-IRAQ BORDERS PRIOR TO D-DAY
  - IRAQ FORCES CROSS KUWAIT BORDERS ON D-DAY (C+18) AND MOVE TOWARDS SAUDI ARABIA, THE AIR WAR BEGINS

Figure 3.1-2. Southwest Asia Scenario Events

Garcia. These ships are ordered to sail for Saudi immediately. The personnel and some equipment of these units are deployed from CONUS by strategic airlift. All elements of this initial force must close in Saudi Arabia by C+14 or sooner.

The ground elements of the initial force, with those of other coalition forces (3 1/3 heavy divisions), establish defensive positions along the Saudi-Kuwait, Saudi-Iraqi borders prior to D-Day. (D-Day, which occurs on C+18, is the date the Iraqi forces cross the Kuwait border.) The airborne division is held in rear assembly areas as the Theater reserve.

Iraqi forces, consisting of 19 divisions in 1st and 2nd echelons formations, are posed to strike into Kuwait and Saudi Arabia on D-Day. An additional 20 divisions are available at various locations in Iraq for employment if required. These ground forces are supported by more than 600 fixed wing aircraft, 190 attack helicopters, and 200 long range surface-to-surface missiles (improved SCUDS). The coalition forces consist of 5 1/3 divisions, supported by about 1000 combat fighters and attack helicopters. Figure 3.1-3 summarizes the force resources for both sides.

On C-Day, two CONUS-based Army Mechanized Divisions prepare for deployment to SWA. These divisions are sealifted to the objective area with a required delivery date (RDD) of C+27. One of these divisions is located at Ft. Stewart, GA and uses Savannah as its seaport of embarkation (SPOE). The other is located at Ft. Hood, Texas and is outloaded at the Beaumont, Texas SPOE.

An early halt of Iraq's advance assures the continual unimpeded operation of air and sea ports of debarkation vital to delivery of follow-on forces and resupply sustainment. Follow-on forces are essential to force the withdrawal of Iraqi forces from Saudi Arabia and Kuwait.

This study's variant of the MRS SWA scenario considers delivery of the two U.S. heavy divisions by WIGs instead of sealift. These divisions are loaded on various fleet sizes of the two WIG configurations to determine if the WIG can deliver them to the area sooner than the sealift RDD.

3.2 UNIT DESCRIPTIONS

Each of the two heavy mechanized divisions selected for deployment by the WIGs have a total tonnage of 96,095 tons. Each division has 17,679 people, 8,350 vehicles, and the primary weapon systems listed in Figure 3.2-1. Appendix A contains a list of the different types of equipment in a heavy mechanized division. Figure 3.2-2 provides a breakdown of the division's contents into Air Force standard categories of outsized, oversized, bulk, and passengers.

3.3 LOADING ANALYSIS

Lockheed's modified version of the Air Force's Airlift Loading Model (ALM) provided the number of loads required by each WIG concept to carry the Army divisions. The model loads aircraft with

INITIAL AIR AND GROUND FORCES

ON D-DAY, C + 18

COMBATANTS	IRAQ	COALITION
PERSONNEL	200,000/400,000*	122,300
TANKS	2,000/4,100*	1,126
AFVS	2,500/4,000*	1,207
ARTILLERY	1,000/2,000*	490
SURFACE-SURFACE MISSILES	210	
MULTIPLE LAUNCH ROCKET SYSTEMS	150	108
ATTACK HELICOPTERS	192	132
COMBAT AIRCRAFT	610	1,000

*TOTAL, PART HELD IN RESERVE

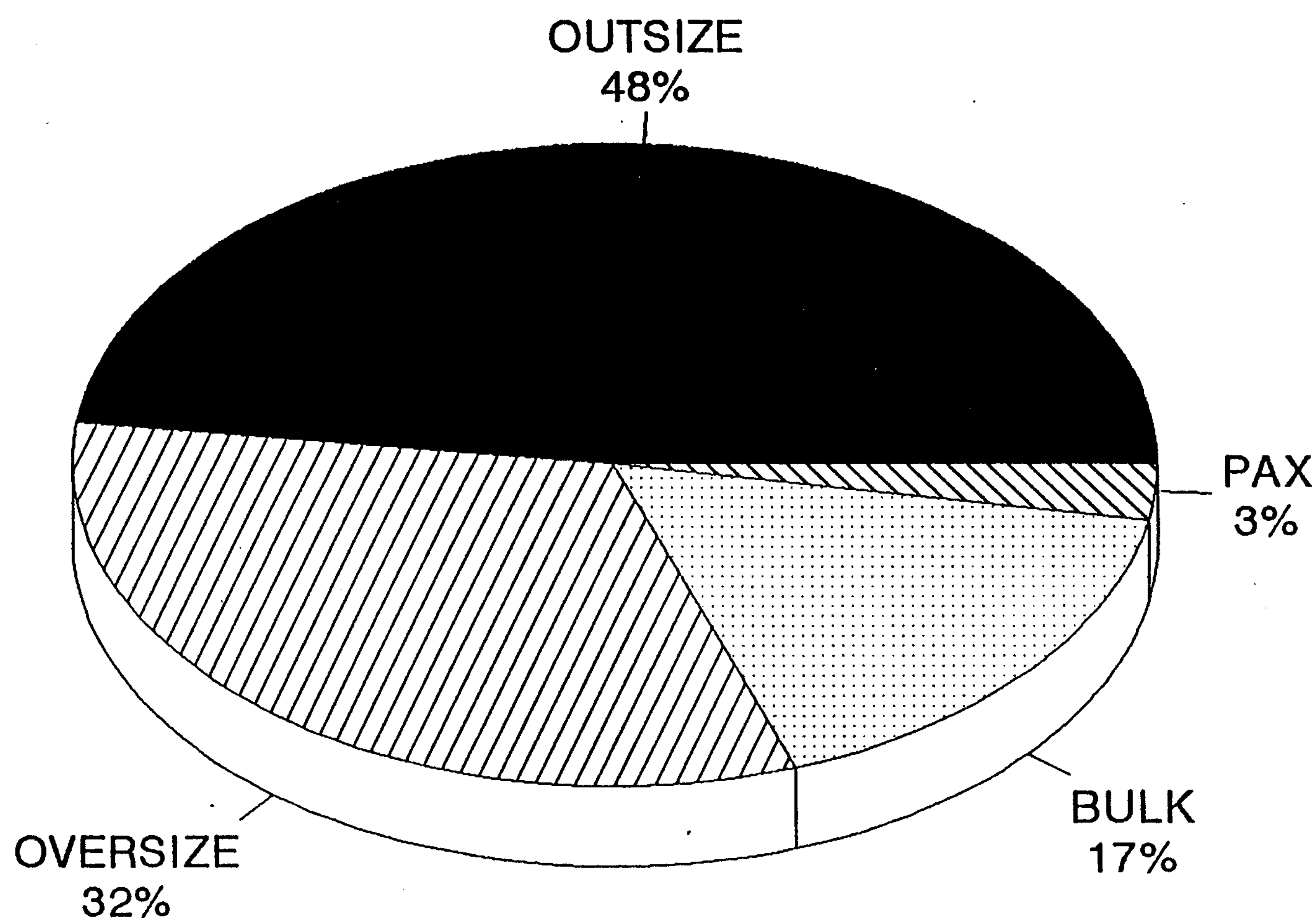
Figure 3.1-3. Initial Air and Ground Forces

COMPOSITION OF MECHANIZED INFANTRY DIVISION

- PERSONNEL: 17,679
- VEHICLES: 8,350
- PRIMARY WEAPON SYSTEMS
  - M1 TANKS: 314
  - M2/M3 INFANTRY/CAVALRY FIGHTING VEHICLES: 533
  - M109, 155MM SELF-PROPELLED HOWITZER: 72
  - MULTIPLE LAUNCH ROCKET SYSTEM LAUNCHERS: 9
  - M-163, VULCAN 20MM AIR DEFENSE ARTILLERY: 36
  - AH-64 ATTACK HELICOPTER: 144

Figure 3.2-1. Composition of Mechanized Infantry Division

CARGO CATEGORY SUMMARY



MECHANIZED DIVISION

Figure 3.2-2. Cargo Category Summary for Mechanized Division

military troops, vehicles, and palletized cargo. It determines if vehicles can be loaded by checking the dimensions of each vehicle with those of the aircraft cargo compartment. User-specified clearances are considered.

The first vehicle selected is the widest that will fit into the aircraft's cargo compartment, observing all payload and loading constraints. Loading begins at the forward left corner of the cargo compartment. Vehicles are loaded side by side, where the next vehicle loaded is the widest vehicle that fits in the remaining space. Loading continues from fore to aft in the cargo compartment.

Secondary to the loading of vehicles is the loading of troops and palletized cargo. Troops may be loaded along the sides of the cargo compartment or in a separate passenger compartment. Troops are either loaded first, at the expense of vehicle payload, or last, after the maximum number of vehicles has been loaded if space and a portion of the allowable cabin load (ACL) remain.

Pallets are loaded only when vehicles no longer can be loaded in the cargo compartment and both space and ACL remain. They can also be loaded on aircraft that carry only palletized cargo.

Figure 3.3-1 lists the cargo compartment dimensions used in the loading analysis of the two WIGs.

3.3.1 Loading Analysis Assumptions

Because of limitations with ALM, many assumptions must be made to load the WIGs. Among these are assumptions about the cargo and passenger compartments.

ALM can model only one cargo compartment per aircraft at a time. The WIG has upper and lower decks that are to be loaded. The cargo compartment ramp is not considered separately in this loading analysis. Therefore, each WIG is modeled as two aircraft, an upper deck aircraft (WIG_U) and a lower deck aircraft (WIG_L). ALM loads these two aircraft in a 1:1 ratio. The total number of loads determined by the model for both aircraft is then divided by two to obtain the actual number of WIG loads.

Because a WIG is modeled as two separate aircraft, the allowable cabin loads (ACLs) for each aircraft must be determined. This is done by calculating the areas of both the upper and lower decks and then determining what percentage each deck is of the total area for both decks. The upper and lower decks are 35 percent and 65 percent, respectively, of the total cargo deck area on the 5000-ton WIG. Multiplying the WIG's total ACL by these percentages produces the ACLs for the upper and lower decks. This approach is independent of deck strength.

The WIG's ACL is based on the distance that the divisions must be moved. The ACL for the 5000-ton WIG is 1725 tons, resulting in an upper deck ACL of 603 tons and a lower deck ACL of 1122 tons. The ACL for the 3000-ton WIG is 600 tons, resulting in an upper deck ACL of 282 tons and a lower deck ACL of 318 tons.

WIG CARGO COMPARTMENT DIMENSIONS

(DIMENSIONS IN FEET)

WIG CONCEPT	AEROCON 5000-TON	AIR FORCE 3000-TON
DECK L x W x H		
- UPPER	311 x 39 x 13.5	196.5 x 28.4 x 14.0
- LOWER	316 x 72 x 19.5	226.3 x 28.4 x 19.0
DECK DOOR W x H		
- UPPER	28.5 x 13.5	28.5 x 14.0
- LOWER	31.0 x 19.5	31.0 x 19.0

Figure 3.3-1. WIG Cargo Compartment Dimensions

Typical cargo compartment clearances of six inches on each side and three inches on the top are used for loading vehicles. Clearance between vehicles is six inches on each side, front, and rear.

ALM can model only one passenger compartment. This compartment is placed on the WIG_U aircraft with a capacity of 350 passengers. The passengers, weighing 300 pounds each, are loaded first.

ALM allows loading through only one cargo compartment door. Therefore, the WIG is loaded through the rear door. Door clearances of six inches on each side and three inches on the top are specified.

3.3.2 Loading Analysis Results

The number of pallets that the WIG_U and WIG_L aircraft carries is determined by calculating how many 463L pallets (size 108 in. x 88 in.) can fit in the upper and lower deck areas. Each pallet weighs 300 pounds and has an average load capacity of 5000 pounds. As shown in Figure 3.3-2, the 3000-ton WIG has a pallet capacity of 168 pallets, with 78 pallets on its upper deck and 90 on its lower deck. The 5000-ton WIG carries a total of 514 pallets, with 170 on the upper deck and 344 on the lower deck.

To move the 192,190 tons of the two heavy mechanized divisions requires 128 loads with the 5000-ton WIG and 370 loads with the 3000-ton WIG. For comparison, movement of these two divisions by more conventional mobility assets requires either 12 loads on 40,000-ton LMSR ships or 1568 loads on 131-ton payload C-5s.

3.4 GROUND FORCE CLOSURE ANALYSIS

Closure times for this WIG study are computed using a simple steady state analysis to insure a balanced and steady stream of aircraft throughout the deployment. Using the Lockheed developed Closure Estimate Model (CEM), the closure times are calculated based on the number of loads generated by the Airlift Loading Model, the interval between takeoffs, and the enroute flight time. The interval used is cycle time divided by the fleet size.

The following input parameters are used in the analysis:

Description	Value
Utilization Rate	24.0 hours per day
Load Time	10.0 hours
Unload Time	4.0 and 10.0 hours
Enroute Refueling Time	1.25 hours
Fleet Size for 5000-ton WIG	10, 20, & 30
3000-ton WIG	10 to 90 in increments of 10
Land Transit Time for	
Ft Stewart Division	2 days
Ft Hood Division	4 days

LOAD CAPABILITIES OF WIG DESIGNS

WIG CONCEPT	AEROCON 5000-TON	AIR FORCE 3000-TON
ALLOWABLE CABIN LOAD, TONS	1725	600
- UPPER DECK	603	282
- LOWER DECK	1122	318
NUMBER OF PALLETS	514	168
- UPPER DECK	170	78
- LOWER DECK	344	90
NUMBER OF LOADS TO MOVE TWO MECHANIZED DIVISIONS	128	370

Figure 3.3-2. Load Capabilities of WIG Designs

Separate routing was done for the deployment analysis for both the 5000-ton and 3000-ton WIG configurations. Figure 3.4-1 shows a world map and the notional routes used by the WIGs for transit between CONUS and SWA. Figure 3.4-2 lists the mission segments and distances actually used in the analysis for the two WIGs; block speeds are posted for the segments selected for each WIG.

Documentation provided by Aerocon Inc. in Reference 2 for the 5000-ton WIG indicates that the full 1,725-ton payload can be delivered to any destination with two refuelings using routes up to 12,341 nm (one-way) at a block speed of 400 knots.

Documentation provided by the Air Force in Reference 3 for the 3000-ton WIG indicates that the range at maximum payload is 4,050 nm with a block speed of 308 knots. This range limitation requires the 3000-ton WIG to be refueled at two enroute stops as well as at the destination.

Parametric variations in WIG fleet size were examined to determine the time required to deliver the Ft Stewart division via Savannah followed by the Ft Hood division via Beaumont to the theater for use in the campaign analysis of section 3.5. Acceptable fleet sizes are those that close the two divisions, preferably by C+18 but no later than C+27.

Figures 3.4-3 and 3.4-4 display the closure periods for 5000-ton WIG fleet sizes of 10, 20, and 30. Both figures allow 10 hours to load each WIG; the difference is in the unloading time. Analysis provided by the Maritime Transportation Management Command in Reference 5 suggests that 4 hours may be adequate for straight-ahead drive-off unloading. If backing is required or if the vehicles must turn during drive-off, then the unloading time could be as high as 10 hours. With the shorter unload time, a fleet of 20 5000-ton WIGs closes both divisions by day C+20; with the longer unload time, the same fleet achieves closure a day and a half later at C+21.5.

Figures 3.4-5 and 3.4-6 provide similar closure data for the 3000-ton WIG. A fleet of 84 closes both divisions by day C+18 with a 4-hour unloading time.

Data for the parametric fleet sizes from Figures 3.4-3 to 3.4-6 are combined in Figure 3.4-7 into continuous curves to permit the selection of specific fleet sizes for other desired closure times. This figure gives fleet sizes for the two concepts to achieve identical closure times. This information expands the applicability of the campaign effectiveness results in section 3.5. Specifically, the campaign result for a fleet of 20 5000-ton WIGs is the same as for a fleet of 74 3000-ton WIGs.

Differences in delivery capabilities for the two WIG point designs are due to their substantial differences in block speed and payload-to-gross-weight fraction. The developers of the two WIGs provided single invariant block speeds, regardless of range, of 308 knots for the 3000-ton design and 400 knots for the 5000-ton design. Major structural design differences between the two concepts exist because the payload-to-gross-weight fraction for the 5000-ton WIG is 0.345, while it is a much poorer 0.2 for the 3000-ton WIG.

DEPLOYMENT ROUTES FOR WIG STUDY

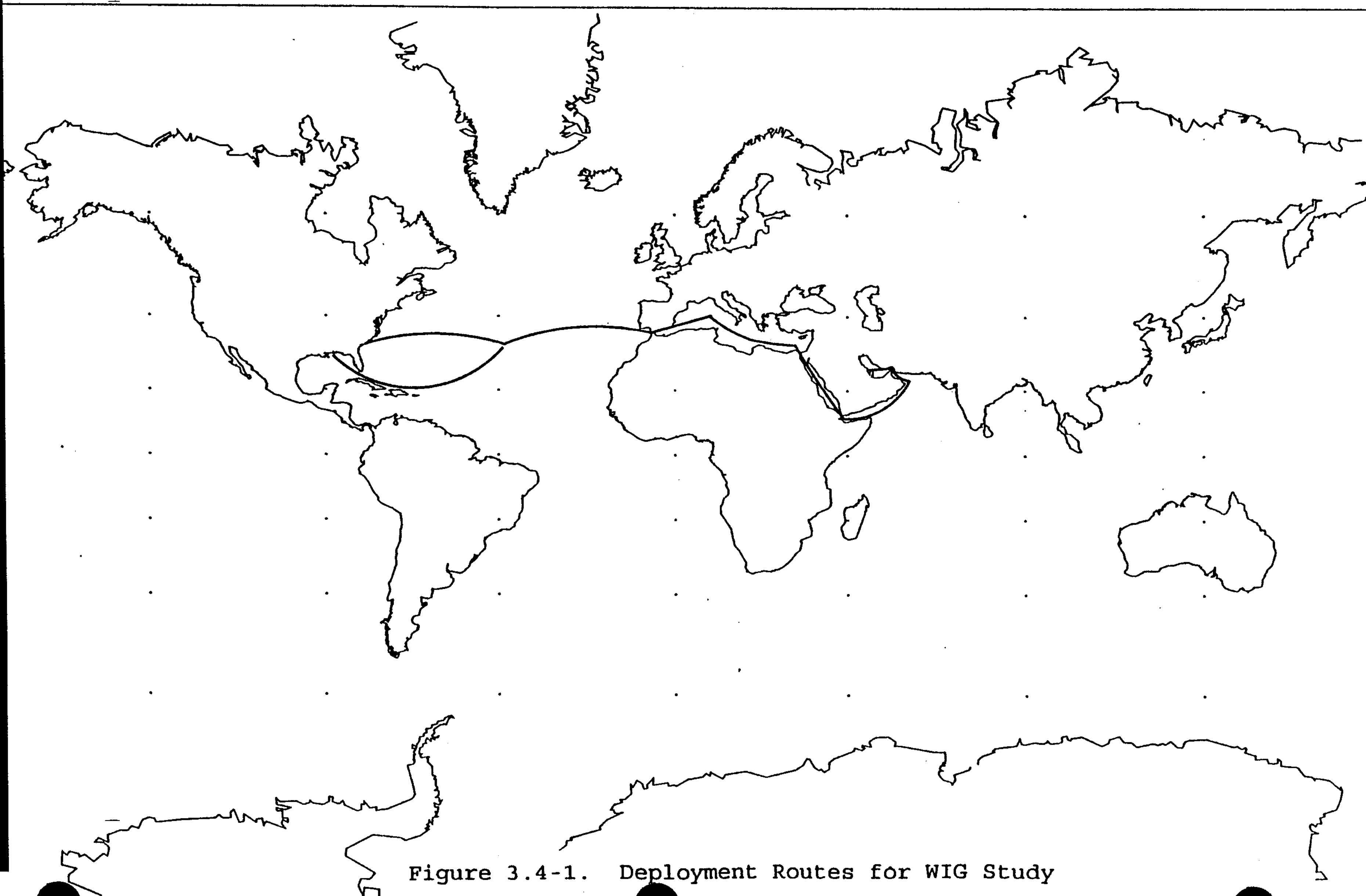


Figure 3.4-1. Deployment Routes for WIG Study

WIG DEPLOYMENT ROUTES TO SAUDI ARABIA

ROUTE	DISTANCE, NM	BLOCK SPEED, KT 5000-TON WIG	BLOCK SPEED, KT 3000-TON WIG
SAVANNAH TO DHAHRAN			
SAVANNAH TO LAJES	2636		308
LAJES TO CRETE	2585		308
SAVANNAH TO CRETE	5221	400	
CRETE TO DHAHRAN	3702	400	308
DHAHRAN TO CRETE	3702	400	
CRETE TO SAVANNAH	5221	400	
DHAHRAN TO LAJES	6287		308
LAJES TO SAVANNAH	2636		308
BEAUMONT TO DHAHRAN			
BEAUMONT TO LAJES	3728		308
LAJES TO CRETE	2585		308
BEAUMONT TO CRETE	6312	400	
CRETE TO DHAHRAN	3702	400	308
DHAHRAN TO CRETE	3702	400	
DHAHRAN TO LAJES	6287		308
CRETE TO BEAUMONT	6312	400	
LAJES TO BEAUMONT	3728		308

Figure 3.4-2. WIG Deployment Routes to Saudi Arabia

CLOSURE TIMES FOR 5,000 TON WIG

LOAD TIME = 10.0 HRS, UNLOAD = 4.0 HRS

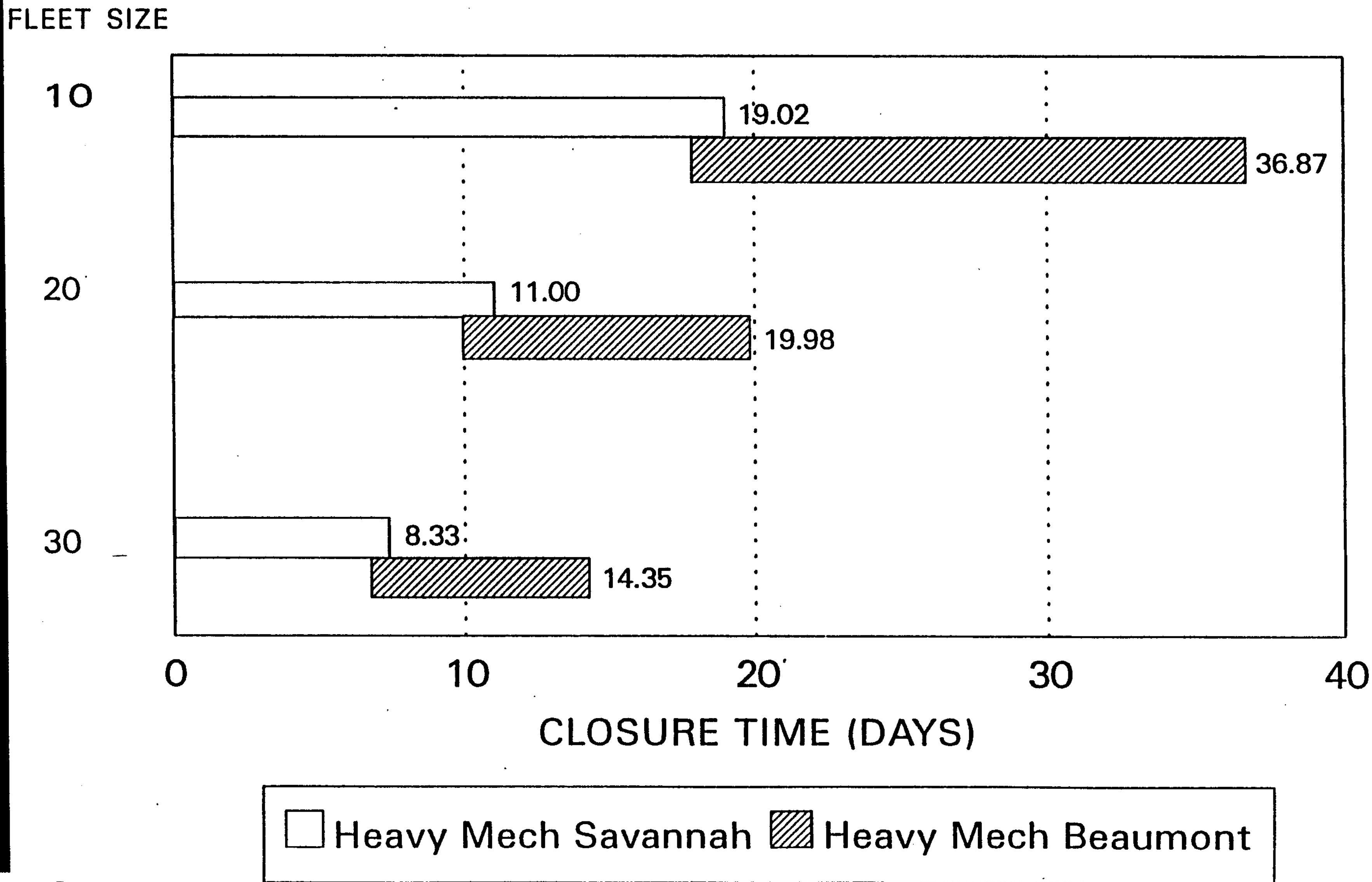


Figure 3.4-3. Closure Ti[illegible] for 5000-Ton WIG, 4-hr Unload

CLOSURE TIMES FOR 5,000 TON WIG

LOAD TIME = 10.0 HRS, UNLOAD = 10.0 HRS

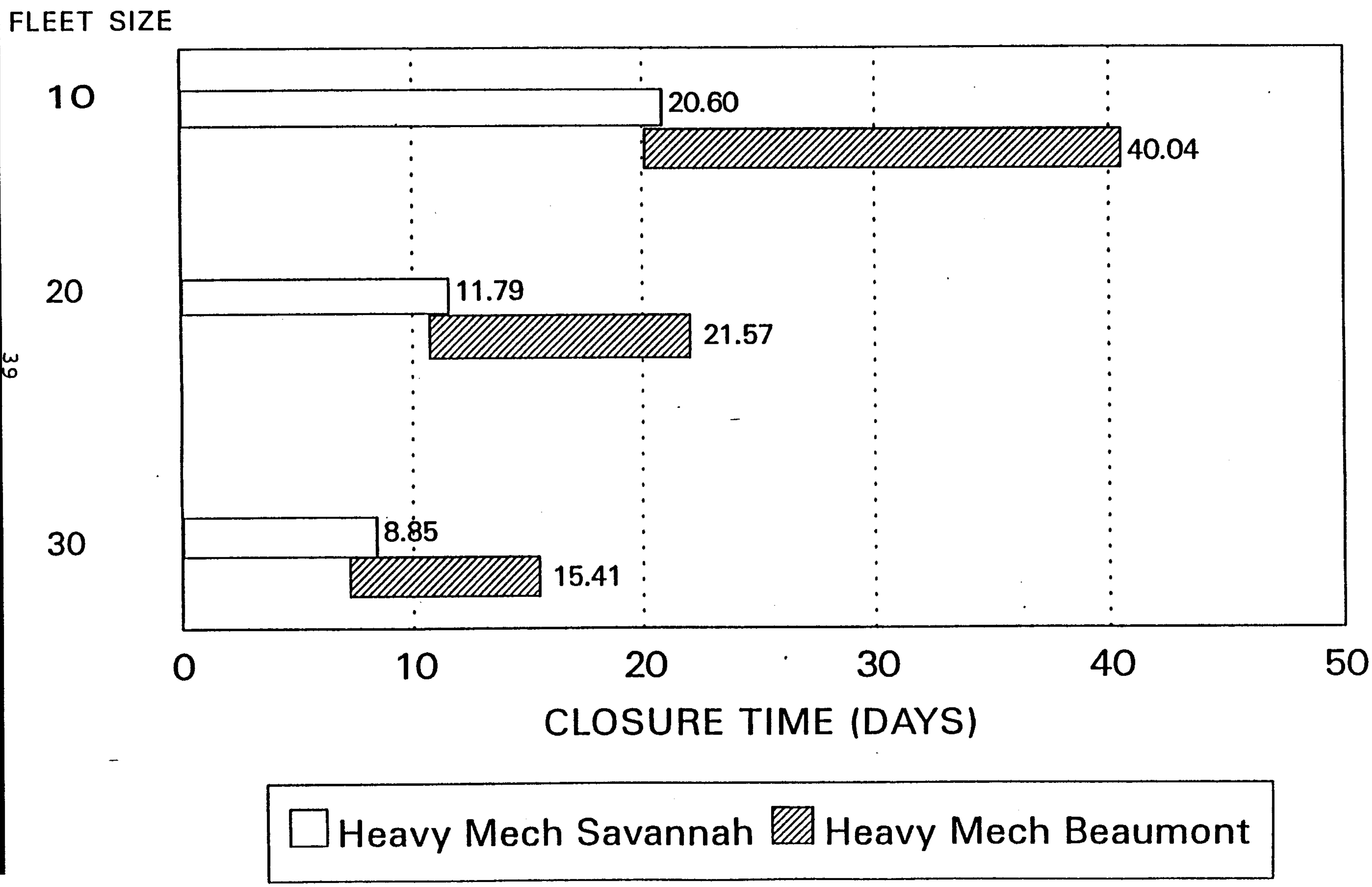


Figure 3.4-4. Closure Times for 5000-ton WIG, 10-hr Unload

CLOSURE TIMES FOR 3,000 TON WIG

LOAD TIME = 10.0 HRS, UNLOAD = 4.0 HRS

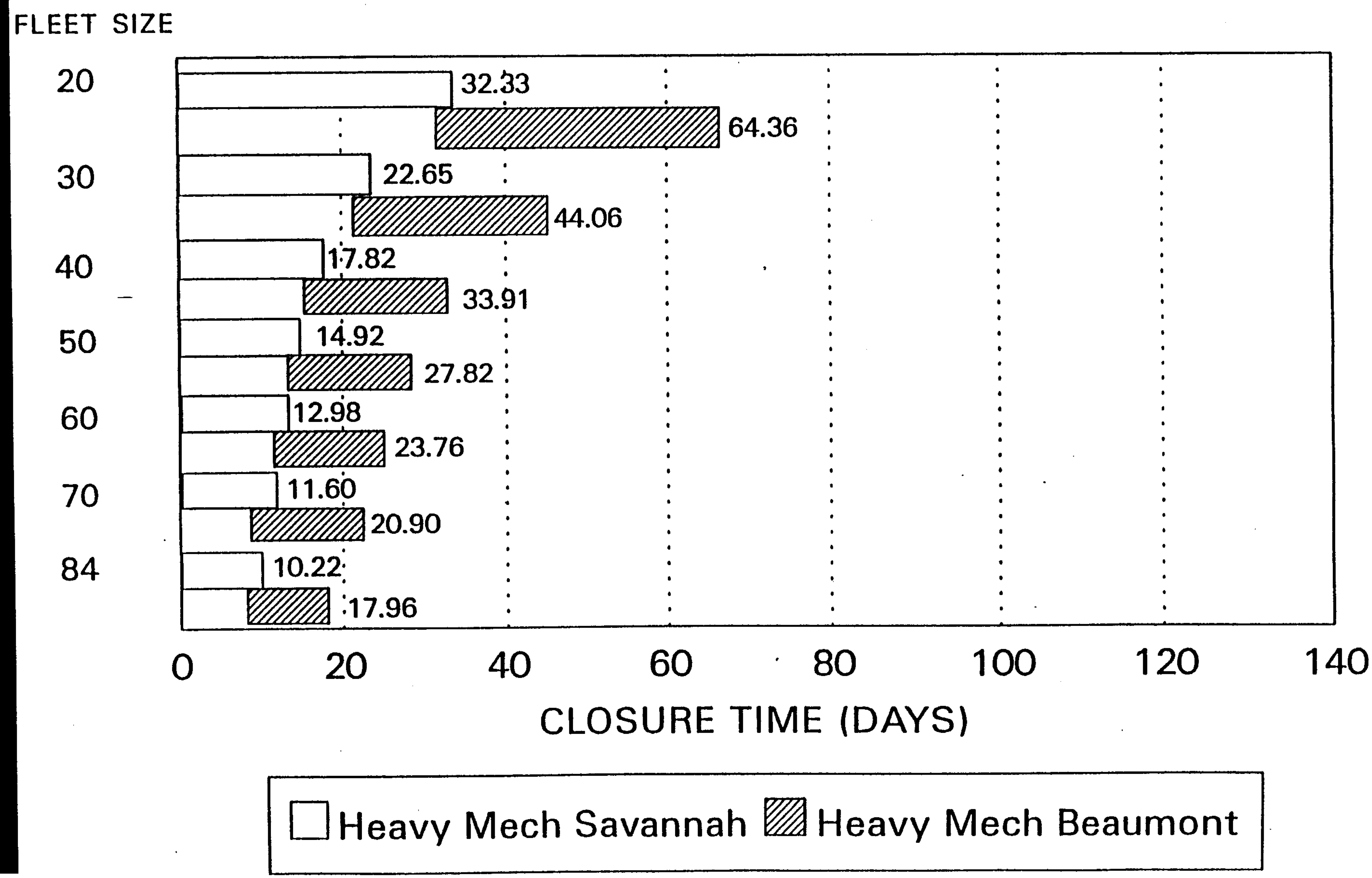


Figure 3.4-5. Closure Time[illegible]r 3000-ton WIG, 4-hr Unload

CLOSURE TIMES FOR 3,000 TON WIG

LOAD TIME = 10.0 HRS, UNLOAD = 10.0 HRS

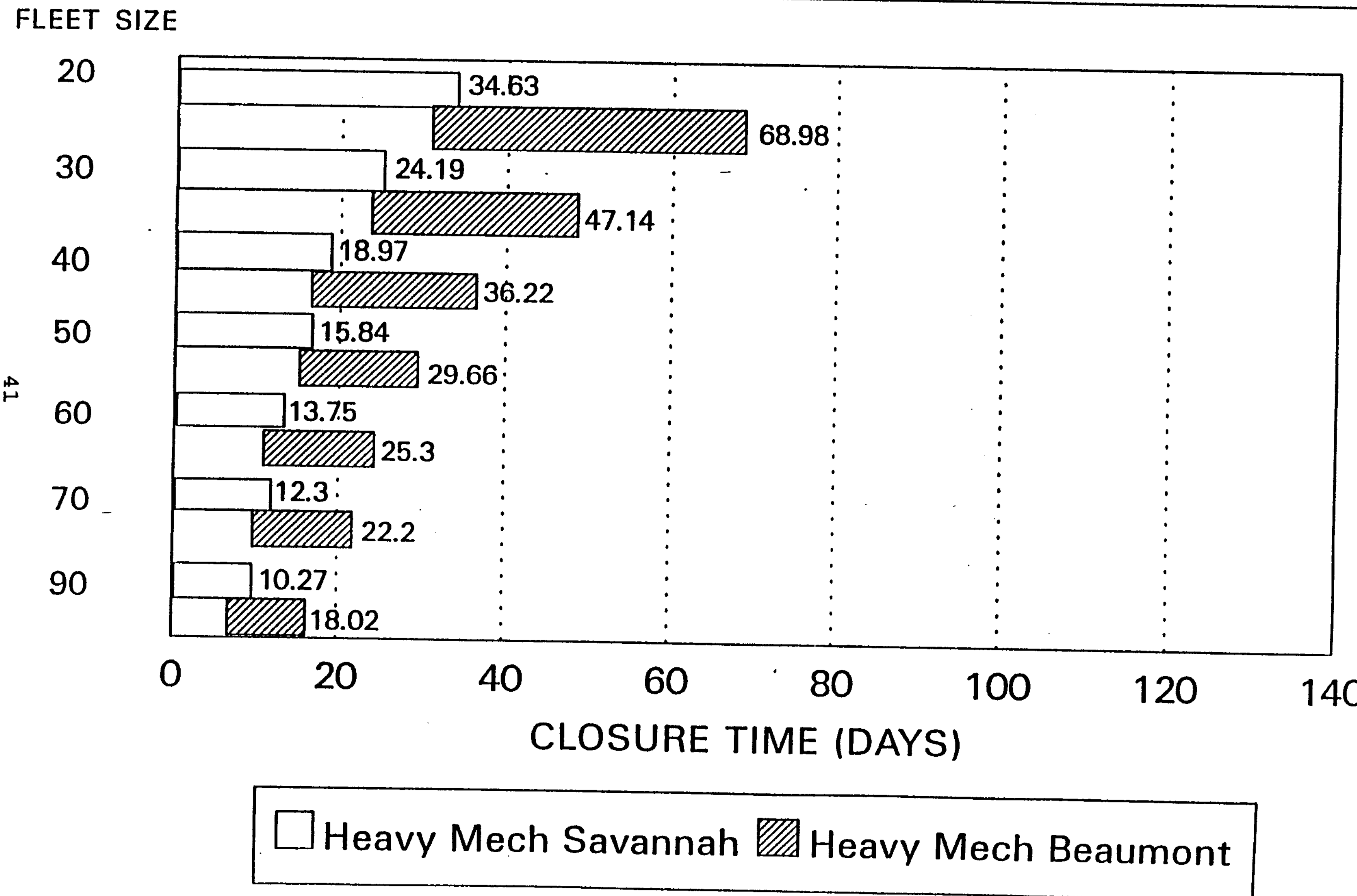


Figure 3.4-6. Closure Times for 3000-ton WIG, 10-hr Unload

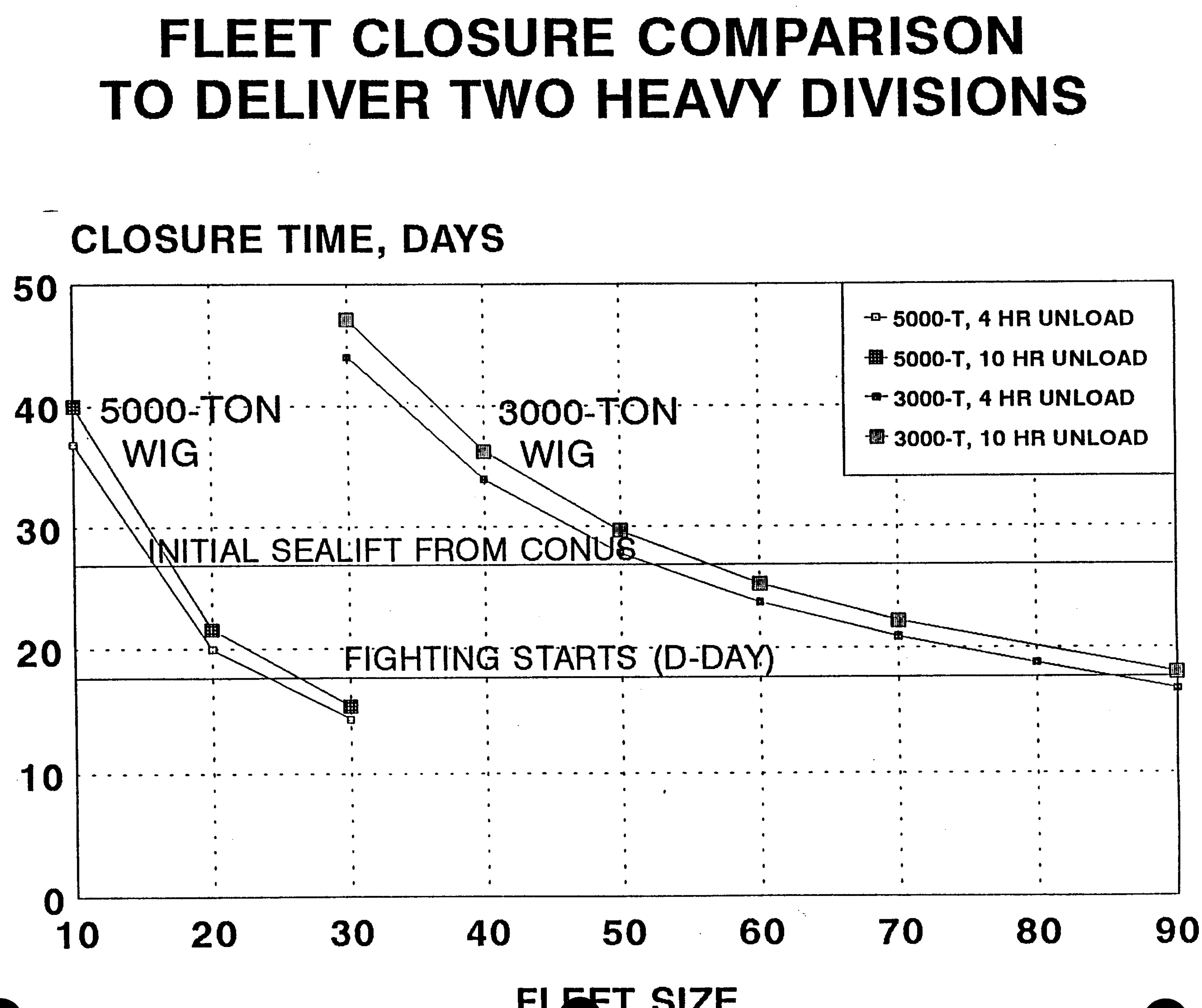


Figure 3.4-7. Fleet Closure Comparison to Deliver Two Heavy Divisions

3.5 WARGAMING AND EFFECTIVENESS ANALYSIS

The combat worth and military utility of WIGs was determined in this study by using Lockheed's version of the Air Force's Tac Thunder campaign simulation model, as described in Appendix B.

The SWA scenario formulated from the Mobility Requirements Study of Reference 1 and discussed in section 3.1 is the setting for evaluating the campaign effectiveness of the two WIG concepts. In this scenario, Iraqi armies invade Kuwait and continue into Saudi Arabia to gain control of the Saudi peninsula and oil fields. Figure 3.5-1 shows Tac Thunder's initial combat unit beddown, avenues of attack, and Allied defense objectives. At D-Day (C+18), Iraqi ground forces begin the attack as they move through Kuwait into Saudi Arabia. The Iraqi Air Force simultaneously initiates offensive air operations. Coalition ground forces occupy prepared defensive positions awaiting contact with Iraqi forces. Coalition Air Forces maintain a defensive posture until the enemy crosses the Kuwait border on D+1. Figure 3.5-2 summarizes Iraqi and Coalition combat air assets actively committed to the campaign.

Three force cases are considered in this analysis. In the baseline case, only surface transport ships are used to deliver heavy combat divisions from CONUS to the theater after the initial light forces are delivered by existing strategic airlift. Two excursions from the baseline case examine WIGs delivering two heavy divisions that were delivered by sealift by C+27. These two cases are for fleet sizes of ten and twenty 5000-ton WIGs, which deliver the two divisions in theater at the times determined by the closure analysis reported in section 3.4.

The principle measure of merit in this campaign analysis is FLOT movement which shows the effect of earlier delivery of forces into the theater. Figure 3.5-3 depicts FLOT movement for the baseline case in which two U.S. Mechanized Divisions deploy into the theater by surface ships unloading at Dhahran. One division arrives at D+7 and the other at D+9. By D+15, the Saudi defense objective line has been penetrated and the port city of Al Jubayl is under siege. At D+25, Iraqi troops are shelling Dhahran, and by D+30, Dhahran is occupied by Iraqi forces. Loss of both ports of debarkation greatly reduces the capability to deliver essential heavy follow-on forces.

Figure 3.5-4 displays the FLOT movement over time when the two divisions are delivered to Dhahran by a fleet of ten 5000-ton WIGs. This lift capability delivers the first division on D+1. The second division is employed into combat one brigade at a time, based on deployment arrival, to reinforce out-numbered coalition forces as rapidly as possible. The second division's three brigades arrive on D+6, D+11, and D+17. FLOT movement for the first fifteen days of combat is less than that of the baseline case, as the first division arrives earlier by WIG than it did by ship. However, the second division is introduced at a slower rate than the baseline case, and FLOT movement decays more rapidly after D+15. Iraqi forces penetration is slowed in the coastal sector where the first division is employed at D+1, but in the Riyadh

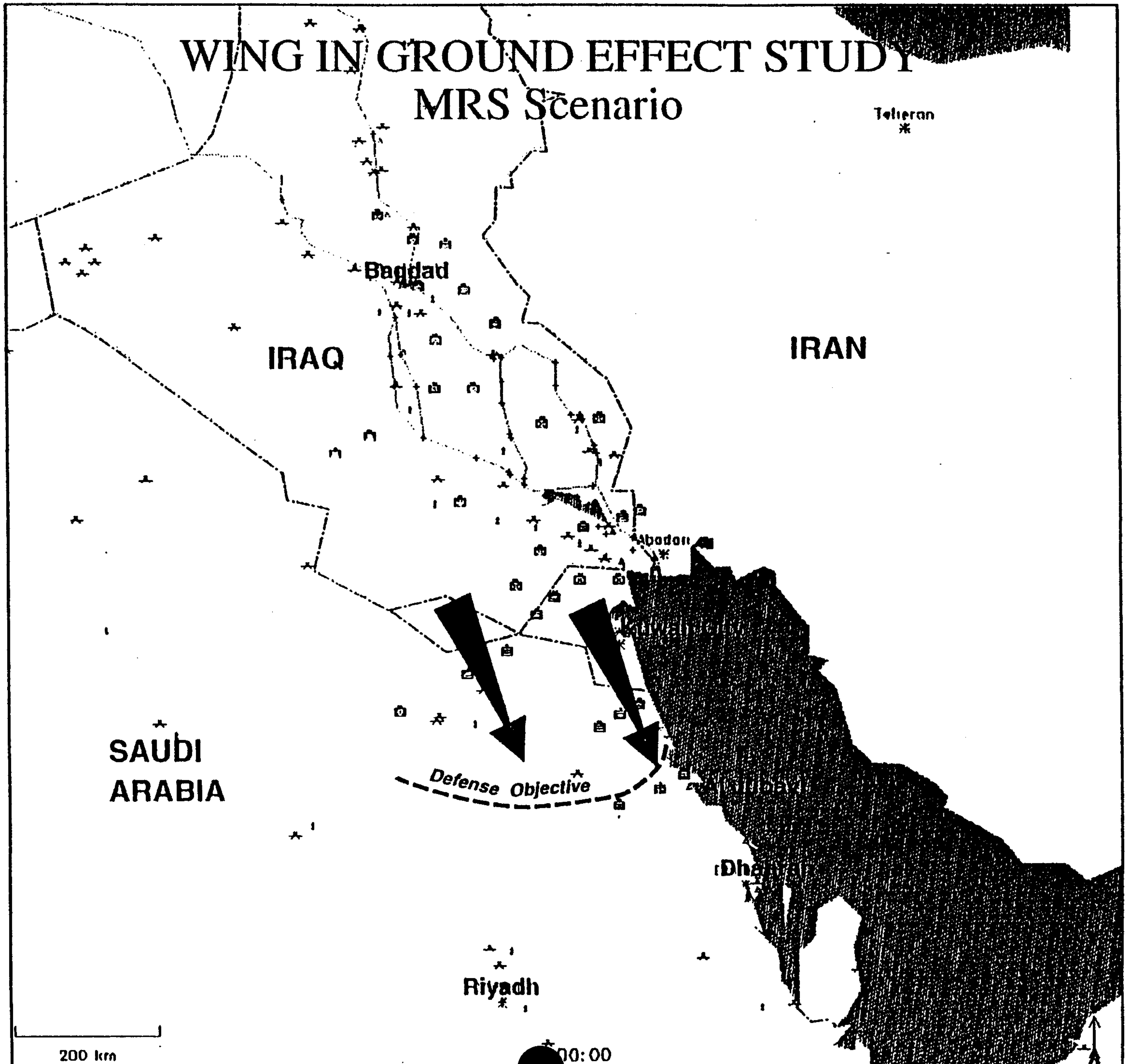


Figure 3.5-1. WIG Campaign Study Scenario Laydown

WING IN GROUND EFFECT STUDY
Combat Aircraft Inventory

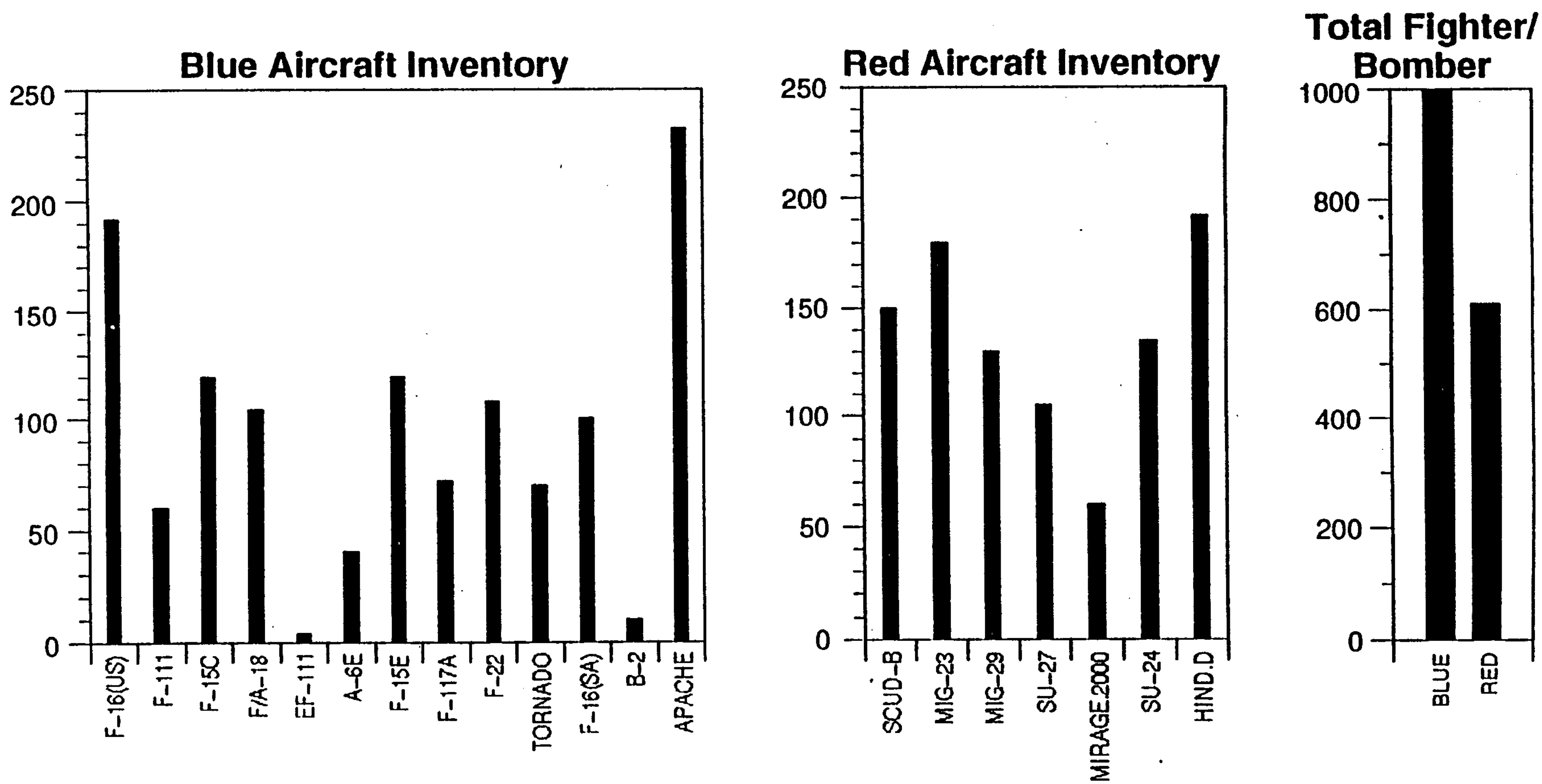


Figure 3.5-2. WIG Campaign Study Combat Aircraft Inventory

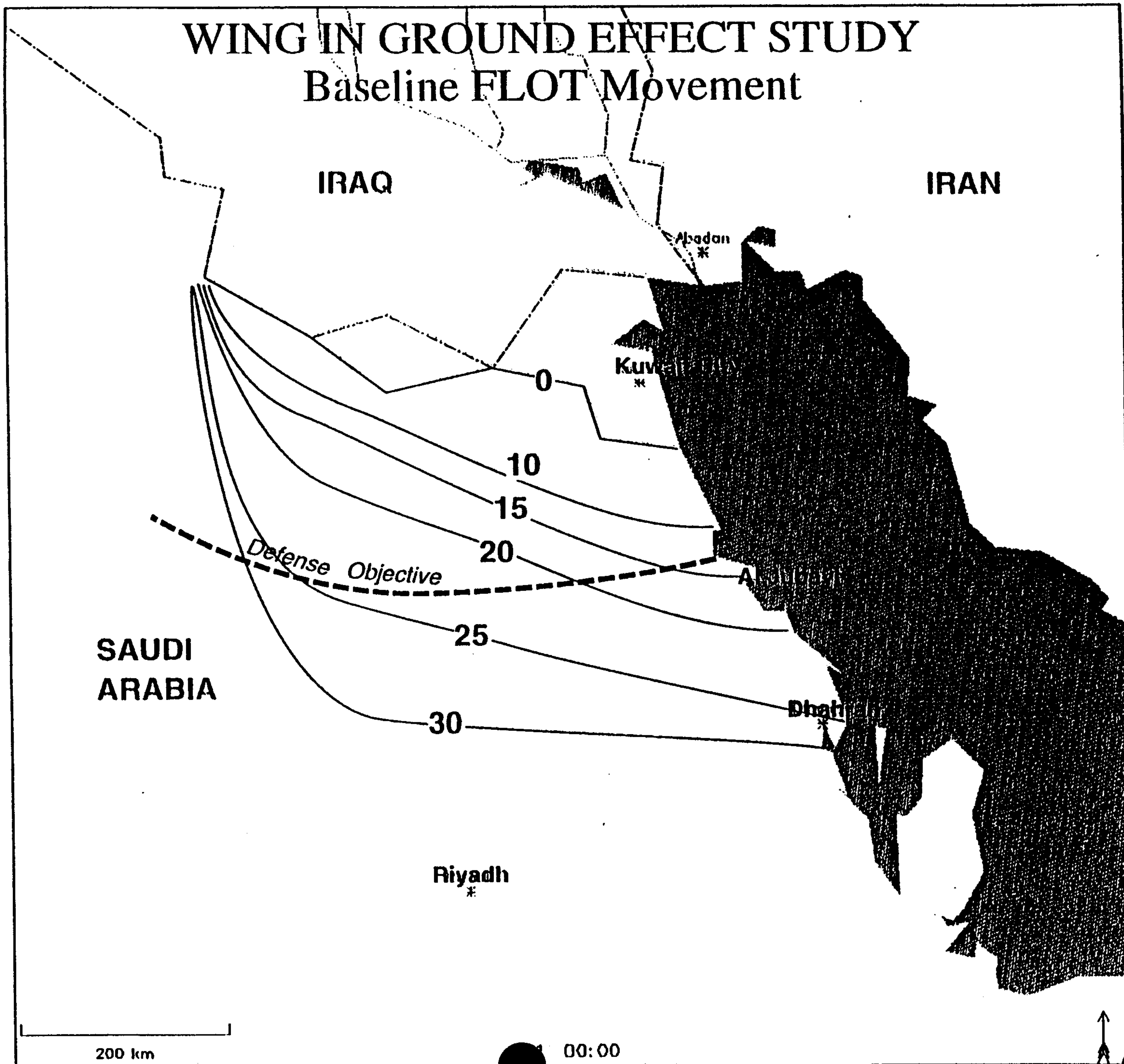


Figure 3.5-3. WIG Campaign Study Baseline FLOT Movement

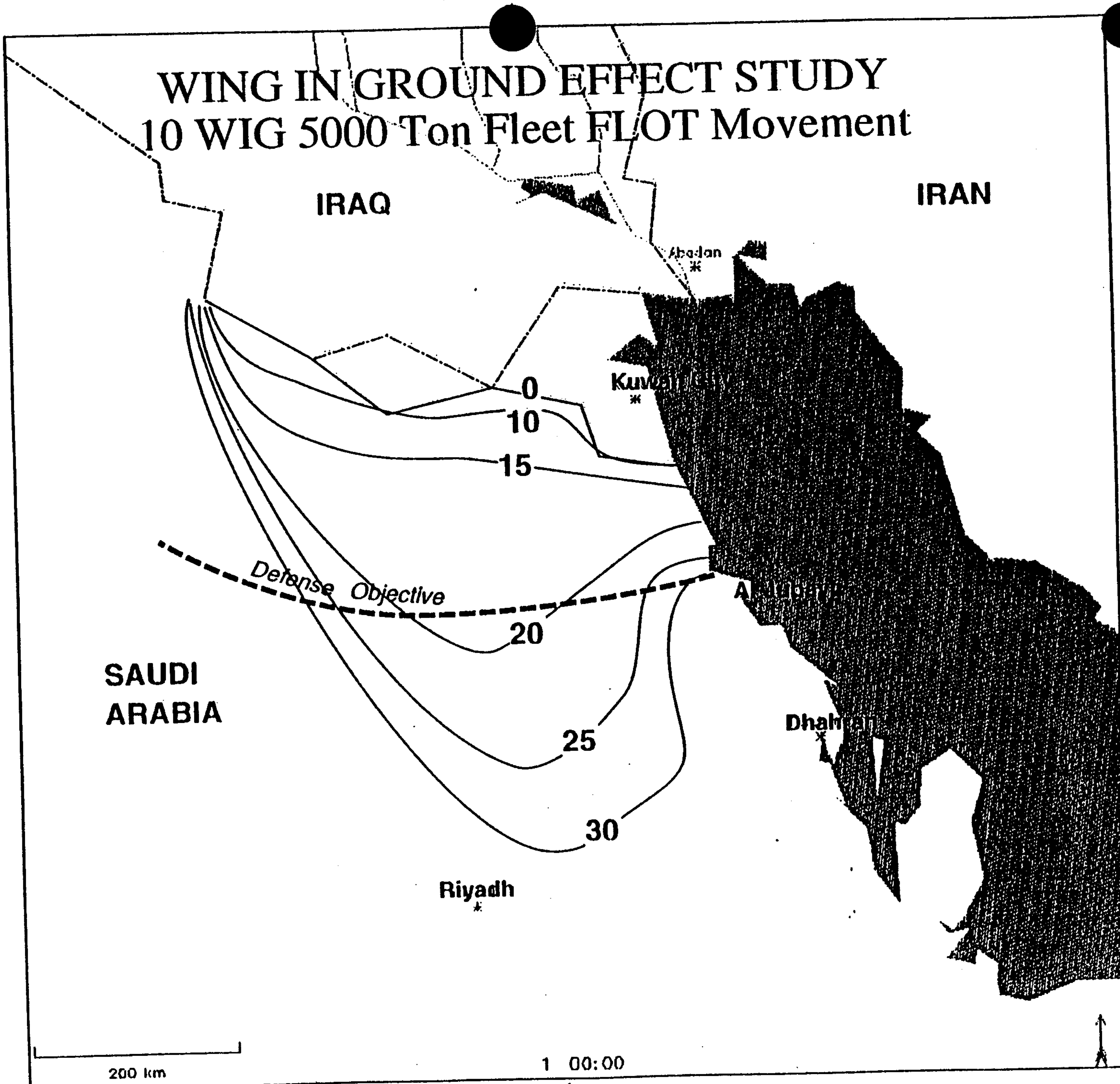


Figure 3.5-4. WIG Campaign Study FLOT Movement with Ten 5000-Ton WIGs

sector, penetration is greater than in the baseline case due to the second division's later arrival and employment. At the end of 30 days, Coalition defenses have been overrun. Iraqi forces isolate Al Jubayl, Dhahran, and the coalition forces in the coastal sector.

Figure 3.5-5 displays the FLOT movement when the two U.S. Divisions are delivered to the theater by a fleet of twenty 5000-ton WIGs. This lift capability delivers the first division prior to D-Day and the second division arrives shortly after D+2. With delivery and employment of the two U.S. divisions at or near D-Day, Iraqi penetrations are stymied. Coalition defensive objectives are met, the port cities of Al Jubayl and Dhahran are never threatened, and the delivery of follow-on forces needed for Coalition offensive operations can proceed as planned.

Invading armies rely on outnumbering their opponent on the battlefield to take and hold ground. Figure 3.5-6 displays the force ratios for the ground combat units. Mechanized Armor Division and Brigade symbols indicate when that division or brigade arrives in theater. The baseline case shows that the engaged force ratio exceeds 2-to-1 (red to blue) at D+6. The addition of the two mechanized divisions did not occur early enough in the conflict to effect the ratio and deter enemy advancements. Coalition forces in prepared defensive positions are soon overwhelmed. With the early introduction of one mechanized division in the ten WIG case, coalition forces maintain a ratio below 2-to-1 longer than in the baseline case. However, the deployment of the second division in one brigade increments does not attrit enemy forces quickly enough to prevent the enemy from achieving a 2-1 edge and achieving a breakthrough on D+13. The arrival of the last brigade reduces the Iraqi advantage, but it is too late to stop the advancement.

The twenty WIG case delivers the initial division prior to D-Day and the second division shortly after D+2. With this delivery schedule, the force ratio of ground combatants is well below 2-to-1 throughout the conflict. Without a large force advantage, Iraqi forces are unable to breakthrough Coalition defenses. The Iraqi invasion is repelled and the Coalition is able to assume the offensive as follow-on forces arrive.

Battlefield force ratio is driven by the amount of armor vehicle kills generated by each side. Figure 3.5-7 plots Iraqi armor vehicles killed by Coalition forces over time. Armor kills in the baseline case are not adequate to control FLOT movement and to achieve defense objectives. In the twenty WIG case, more armor kills occur sooner which dramatically impacts FLOT movement, as previously discussed. Initial armor kills in the ten WIG case are comparable to those of the twenty WIG case, although the second division is inserted later by the ten WIG fleet, but armor kills fall off beyond D+5 and the FLOT moves deeper into Saudi Arabia.

3.6 SUMMARY OF EFFECTIVENESS RESULTS

Campaign analysis for the WIG concepts links lift capability with combat outcome. The baseline lift capability deploys two heavy divisions by sealift which is insufficient to meet the

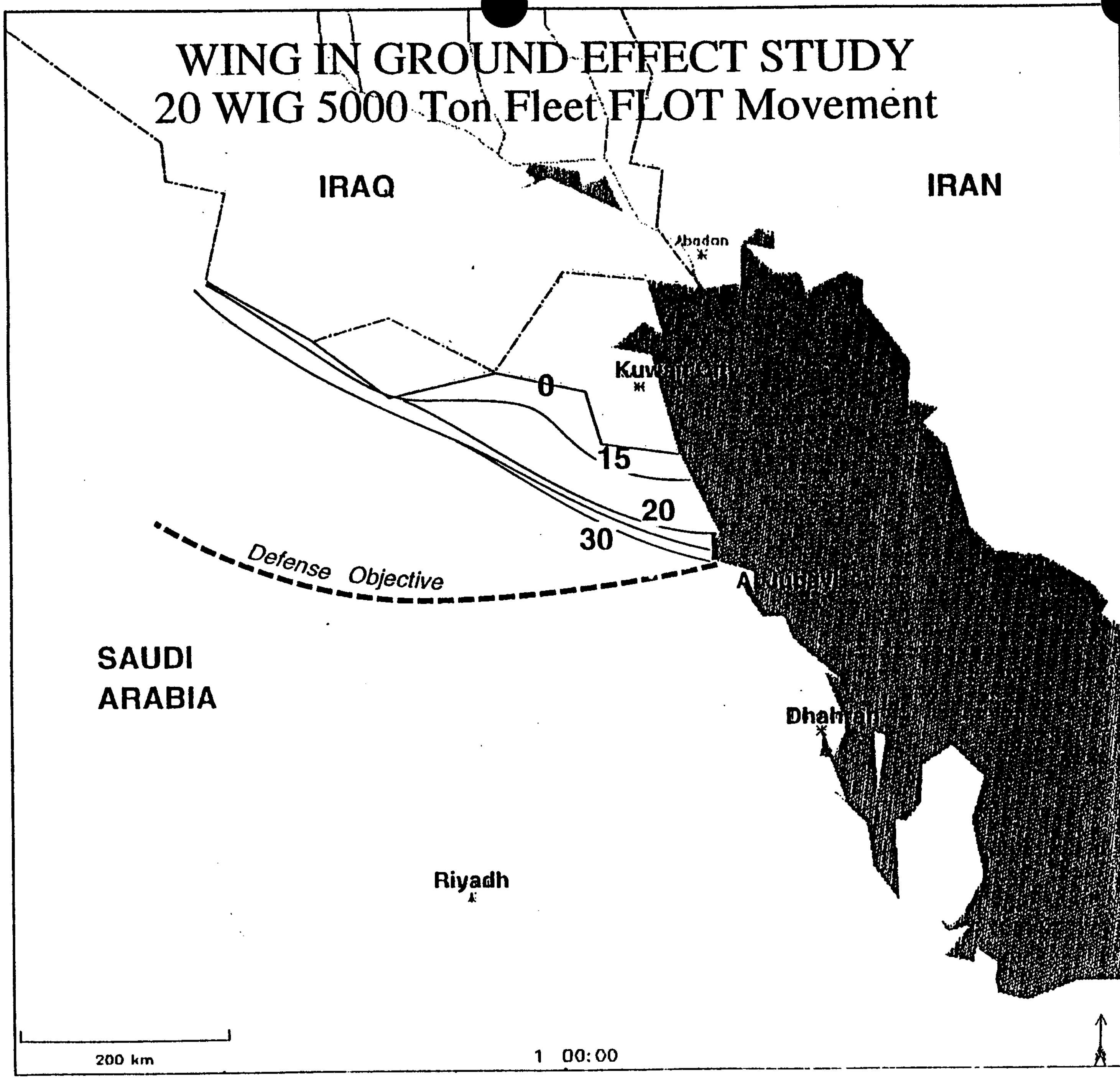
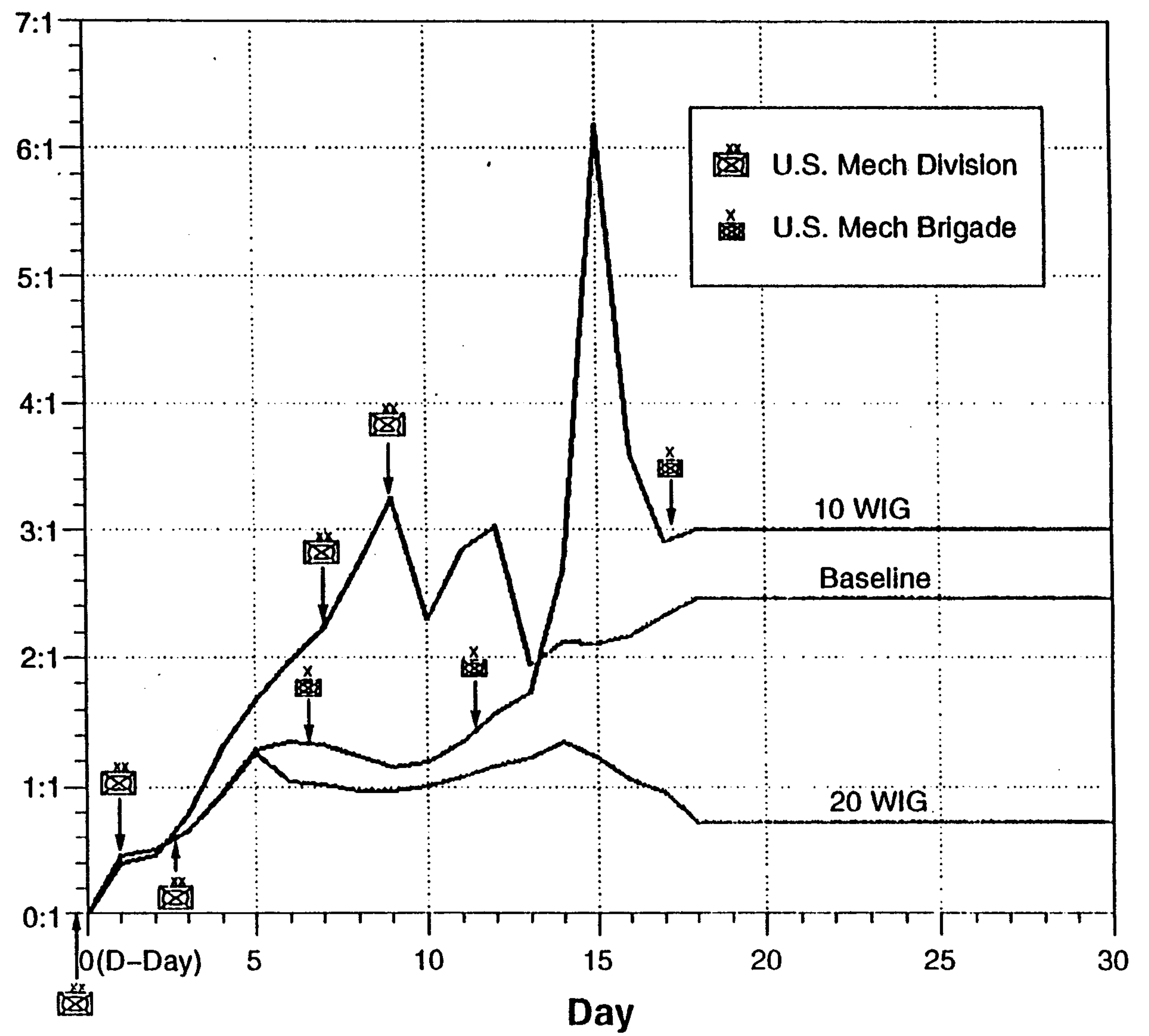


Figure 3.5-5. WIG Campaign Study FLOT Movement with Twenty 5000- Ton WIGs

WING IN GROUND EFFECT STUDY
Engaged Force Ratio



Force Ratio = $\frac{\text{Red Online Combat Equipment}}{\text{Blue Online Combat Equipment}}$

Figure 3.5-6. WIG Campaign Study Engaged Force Ratio

WING IN GROUND EFFECT STUDY
Iraqi Armor Killed

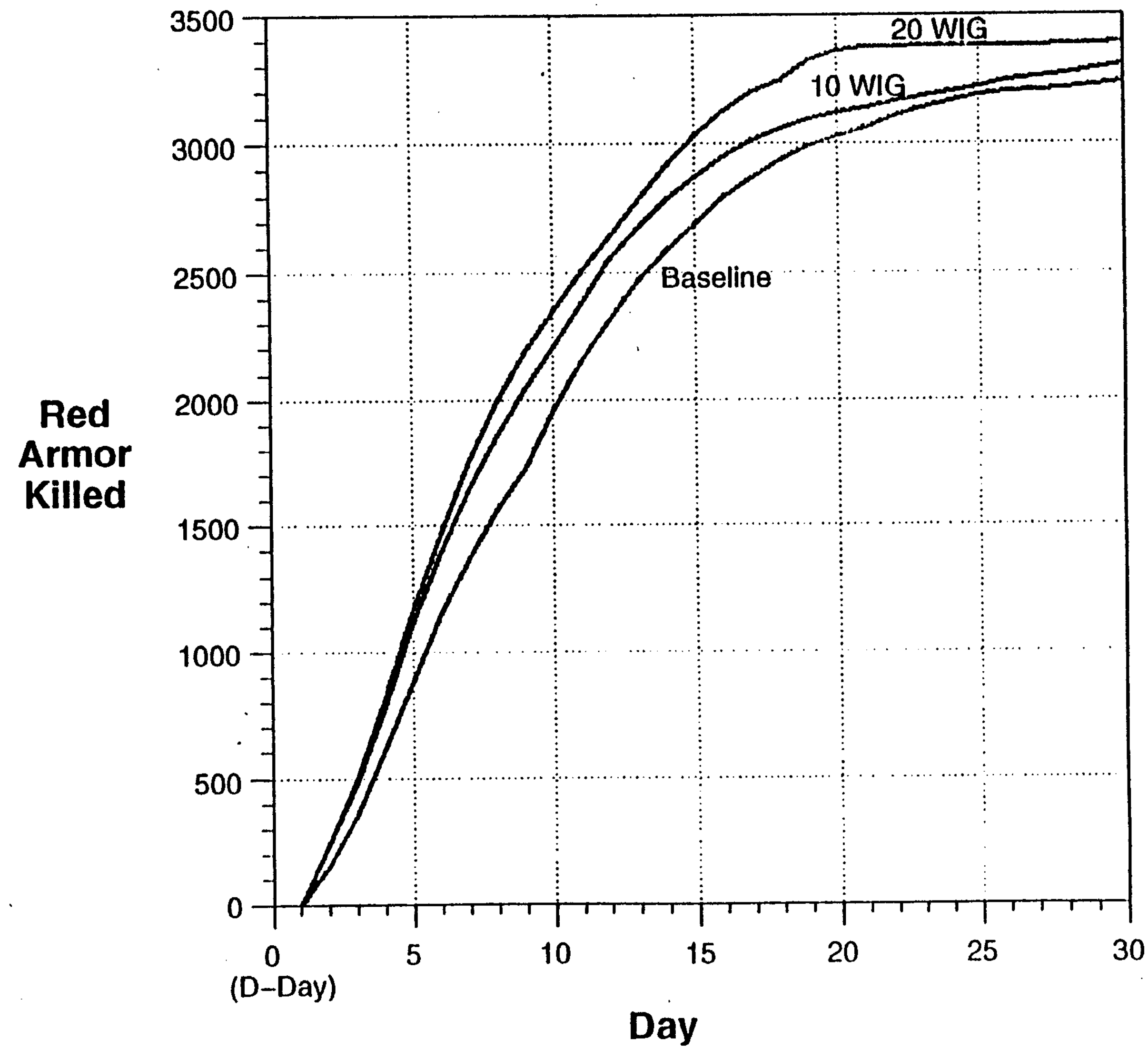


Figure 3.5-7. WIG Campaign Study Red Armor Kills

demands of the SWA scenario. Utilizing a high speed, high volume/mass transport system is essential to satisfy the mobility requirements of this scenario. A 5000-ton WIG has the capacity necessary to deliver the required forces with a fleet size of 20 vehicles; a fleet size of 10 vehicles is inadequate.

From Figure 3.4-7, shown earlier, a fleet of 74 3000-ton WIGs is required to close the two heavy divisions in the same time period as a fleet of 20 5000-ton WIGs, with the same campaign results.

4.0 POTENTIAL COMMERCIAL APPLICATIONS

4.1 IDENTIFICATION OF CANDIDATE APPLICATIONS

The use of WIGs in commercial applications will depend on their ability to compete with other forms of transportation on a cost effective basis. The WIG has the potential to provide a unique capability, which is not found in either aircraft or ships, by offering the opportunity to deliver cargo that usually must be carried by ships, at speeds generally associated with airlift. It is not anticipated that WIGs will be a replacement for either sealift or airlift; rather, they will fill an existing requirement which complements ships and aircraft by providing the capability to efficiently transport time sensitive, high value, large, outsized, or heavy cargo loads at high speeds.

Lockheed anticipates that very large WIGs, such as the Aerocon 5000-ton Wingship, will not be produced in the near future. There will be a development cycle which will require smaller variants to develop the necessary databases and address the technology issues. During the operational development of smaller classes of WIGs, it will also be necessary to explore the potential of this type of vehicle to operate out of ground effect. Questions on the desirability of operations out of ground effect and on practical altitudes must be resolved. We also anticipate that the initial class of WIGs, though smaller, would become operational vehicles for military, commercial, and civilian law enforcement use.

Our initial studies suggest that the first WIGs may be suited for the applications listed in Figure 4.1-1. These WIGs will probably be capable of carrying 50,000 to 100,000 pounds of cargo for ranges of up to 6000 nautical miles. This type of long range vehicle with the proper cargo box design could have an immediate commercial applicability by providing high value and/or time sensitive outsized commercial cargo transport and an efficient, time saving automobile ferry. Other variants of this class of WIGs could support law enforcement by providing a very fast response vehicle for drug interdiction and a fast customs and immigration patrol capability for the Border Patrol. It could also provide the Coast Guard a much faster response capability for their maritime patrol and search and rescue (SAR) activity. Finally this class of WIG would also provide rapid response capability for environmental disaster teams (such as responding to an oil spill), or transporting personnel and relief supplies to an island or coastal community which has suffered an earthquake, hurricane, tidal wave, or other disaster where the infrastructure had been damaged or destroyed.

CANDIDATE COMMERCIAL APPLICATIONS

- OUT-SIZED COMMERCIAL CARGO TRANSPORT
- HIGH-SPEED AUTOMOBILE FERRY
- CIVILIAN LAW ENFORCEMENT - DRUG INTERDICTION
- CUSTOMS AND IMMIGRATION PATROL
- COAST GUARD PATROL AND SEARCH AND RESCUE
- DISASTER RESPONSE

Figure 4.1-1. Candidate Commercial Applications

4.2 ANALYSIS OF CANDIDATE APPLICATIONS

Figure 4.2-1 summarizes our preliminary estimates of requirements for the initial class of WIGs for use in non-military applications. These requirement values are a best estimate, and establish a baseline for a more detailed requirements analysis. Further analysis is needed to predict some of the requirement values, as evident by the TBD notation on the figure.

4.2.1 Out-Sized Commercial Cargo Transport

The aerodynamic efficiency of a vehicle operating in ground effect will relax some of the configuration constraints that now drive the designs of standard cargo aircraft. Further, the sea keeping efficiency and other technology advantages of a twin hull vehicle make catamaran and spanloader design technology much more practical, opening up the potential for new and innovative configuration ideas. These things combine to make outsize cargo boxes more feasible while maintaining a high level of operational and fuel efficiency.

The operational experience and databases necessary for this type of vehicle to compete in the commercial market place will come from the initial military use of these WIGs as high speed, outsized cargo carriers and from some of the alternate military missions now being proposed. As operational experience is gained and the efficiency of the vehicle proven, the commercial transport industry will begin to look for ways to exploit the smaller WIG's capabilities. When the commercial viability of this class of WIGs is shown, a strong constituency will emerge and make development of heavy lift WIGs more economically feasible.

4.2.2 High Speed Automobile Ferries

The initial class of small WIG vehicles will be ideally suited for use as automobile ferries. The first application will most likely be to replace existing ferries, especially those that take more than one hour to complete a crossing. For many current ferry crossings, few special passenger accommodations would be required in the replacement WIG since the crossing time would be reduced to under an hour. For crossings that lasted much more than an hour with the WIG, passenger accommodations could be provided that are similar to those currently available on current automobile ferries.

Future applications could include longer range operations along coast lines and between islands such as those that make up the State of Hawaii. These operations are similar to auto-train operations except travel speeds would be nearly the same as flying. It would provide the ability to board a ferry with your own automobile, travel at near aircraft speeds, and have transportation at your destination. The elimination of overnight expenses and auto rental expenses could make this type of venture very cost competitive with both normal driving and airlines.

POSSIBLE REQUIREMENTS FOR COMMERCIAL WIGs

ISSION	PAYLOAD 1000 LB	RANGE 1000 NM	SPEED KNOTS	CARGO BOX LxWxH, FT
UT-SIZED OMMERCIAL CARGO	75 - 200	2 - 6	300 - 400	TBD
IGH-SPEED UTO FERRY	50 - 300	1 DAY W/O REFUEL	150 - 400	TBD
AW ENFORCEMENT RUG INTERDICTION	TBD	1 - 3	300 - 400	TBD
USTOMS AND MMIGRATION PATROL	TBD	1 - 3	300 - 400	TBD
OAST GUARD EARCH AND RESCUE	TBD	1 - 3	300 - 400	TBD
ISASTER RESPONSE	50 - 100	2 - 6	300 - 400	TBD

Figure 4.2-1. Possible Requirements for Commercial WIGS

4.2.3 Civilian Law Enforcement - Drug Interdiction Vehicle

The current speeds of surface ships used in drug interdiction require that they remain at sea for many days. Further, many of the drug runners are using high speed power boats that can outrun many of the patrol craft used in interdiction operations. The WIG would be able to respond from a port and intercept a suspect ship several hundred miles out to sea in less than an hour. The interceptor would be able to use radar and other active search modes without out fear of the suspect detecting its operations and running away. No drug runner would be able to outrun the intercepting WIG as it would have overwhelming speed advantage (at least three to five times faster). The cost savings of having these interceptors able to respond from port, having the ability to run down any drug runner, and being able to operate with fewer interceptors will provide more cost effective interdiction operations. It would also be very easy to arm the WIG in a manner similar to current drug interdiction patrol boats.

4.2.4 Customs and Immigration Patrol

The Border Patrol would gain the same intercept advantages with WIGs that would be available to drug interdiction forces. In addition, if patrols of long shore lines or large open ocean areas were required, the WIG would be able to effectively patrol an area which currently requires many conventional patrol boats. The high speed of the WIG would make random patrols much more effective, since very few boats would be able to get out of the way even with warning that a patrol boat had left port. Again, with fewer vehicles required for patrol operations and long range intercept from port possible, there would be distinct cost advantages.

4.2.5 Coast Guard Patrol and Search and Rescue

The Coast Guard can exploit the WIG for patrol activities in the same manner as law enforcement and customs and immigrations. Rapid response from port offers the potential for significant cost advantages. In addition, the WIG's ability to respond rapidly from port combined with current airborne search capability provides a much faster response time for pick up of survivors of ships and aircraft lost at sea . The hours that are currently required to get a ship into an accident site for pick-up can easily make the difference between everyone being lost, and the survivors being picked up alive.

4.2.6 Disaster Response

The speed of the WIG will enable disaster response teams to reach many disaster areas much faster than they can now. In an oil spill for instance, the increased speed will allow the response team to have control booms in the water a few hours after leaving home port. The less the spill spreads, the faster it can be

cleaned up. This rapid response, and the ability to get the spill controlled away from the shore will minimize the potential for the contamination of prime shore areas and greatly reduce the impact to wild life in the area. For response to a natural disaster that has destroyed the existing infrastructure, the inherent amphibious capability of the WIG could greatly reduce response times. The ability to put supplies and rescue teams in very quickly could save hundreds of lives. In both of these cases, rapid response is essential to mission success, and in both of these cases, the response time is currently driven by the speed of slow conventional surface ships.

4.3 ISSUES ON COMMERCIAL APPLICABILITY

The transition from military to commercial use will depend on the operational capabilities of the WIGs, and the experience that they have had with safety. Figure 4.3-1 illustrates the concerns with safety that must be addressed prior to full scale commercial operations.

When the WIG's safety and reliability are proven through military usage, commercial enterprises will try find cost effective ways to exploit their capability for meeting the needs of the civilian community. This transition will be helped by the fact that the projected sizes and performance of WIGs being considered for military use will lend themselves to commercial operations. The need to design the military WIGs so that they will be able to use existing commercial port facilities in both the United States and host countries, will further enhance the transition from military to commercial use.

In the commercial market place, the WIGs must prove themselves to be cost effective to be competitive with alternate means of transportation. To determine the cost effectiveness of the various vehicles, it will be necessary to conduct studies which compare the costs and efficiencies of both air and sea shipments to WIG shipments. For example, the current cost of acquiring a large ship and a large size cargo aircraft are similar. Acquisition costs for a roll-on/roll-off ship and a C-5 aircraft are both about 225 million dollar. There are also costs associated with the operation of these vehicles. The cost per pound or ton of moving cargo from point A to point B must include the operational costs such as the costs of fuel, maintenance and the crew, and amortize the cost of the ship or aircraft for the portion of its life span used in transporting that cargo. This amortization must also include things other than the direct costs such as the cost of money to purchase the vehicle and the time to load and unload cargo. There are many other factors which must be determined and investigated. The fact that the analysis must include both air lift and sea lift and develop a reasonably accurate cost per pound for a WIG to transport cargo makes this study different and more difficult than similar studies that have looked at just sea lift or just air lift.

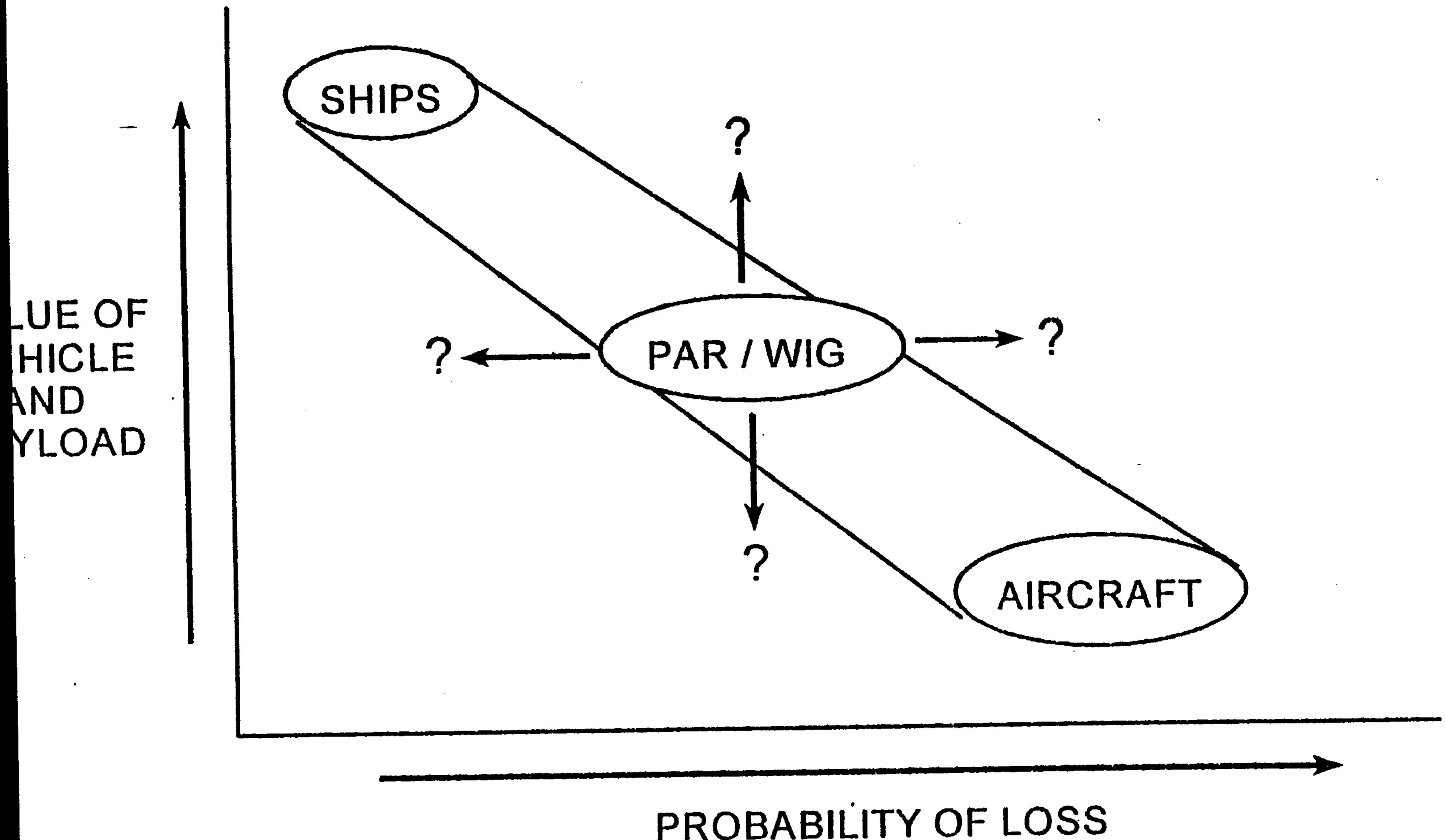


Figure 4.3-1. The amount of risk associated with the operations of a vehicle must be balanced with the risk of loss of the cargo in the vehicle and the vehicle itself. WIGs probably will not reach full size potential until there is a data base of operational experience to determine the amount of acceptable operational risk.

WIG-002b

There are many technical issues that must be addressed. The basic design of the WIG is only a part of the problem. To grow to the full size potential, the WIG will require extensive structures and materials work. There is no proven direct translation or scaling of current aircraft structural design practices to the structural layout that will be required to support the huge WIG vehicles currently being proposed. Not only must the structure support the large vehicle, it must also provide the strength to absorb the impacts associated with takeoff and landing on the water. Ship design practices will probably offer some insight into the problem, but this will require study and familiarity with both aircraft and ship design practices. This design problem alone will probably be sufficient to require that the smaller classes of WIGs discussed earlier in this section be the starting point of serious WIG development.

Resolving the structural design and strength issues may require development of new materials if the structural fraction is to be held to reasonable proportions. In addition, all materials used in the WIG must be compatible with extensive exposure to sea water, salt spray, and the marine atmosphere. It may also be necessary to develop high temperature, salt resistant materials for use in the engines.

Operationally, there is no data base available for a large WIG concept. Many questions must be answered. For instance, is it practical for the WIG to have a free flight capability out of ground effect? If it is, how high should it be able to go, and is there a point where going above a certain altitude will cost more that it is worth? In addition, there are many questions about weather penetrations and high sea state operations that must be answered. The only operational databases are resident in the Former Soviet Union and they are very limited in nature. These databases must be created through development testing and follow-on military operations.

The WIG offers a major improvement in our ability to move large cargos at high speeds. To exploit this capability we will require a well planned program. The concept must be proven to be reliable and affordable in the commercial market place. Continuing study of the technical issues, the cost effectiveness issues, and determining what are the real requirements will be the key to a successful affordable program.

5.0 COST ANALYSIS

To estimate the acquisition and life cycle costs for the two WIG point designs, we used our Lockheed Life Cycle Cost Model (LLCCM), which is described in Appendix C. These WIG concepts are non-conventional air vehicles for which there are minimal program and configuration data. To overcome this lack of data, we established a set of program cost ground rules and made many assumptions about configuration details. These ground rules, assumptions, and the resulting cost data are presented in the following sections.

5.1 COSTING GROUND RULES

The basic ground rules used for this study are as follows:

- o Year of Economics(constant dollars): 1994
- o Technology availability date(TAD): 1997
- o Compressed, accelerated EMD begins building: 1998
  - -- One-quarter scale airframe as a static and fatigue test article
  - -- One full scale test vehicle for flight testing, evaluation, and qualification, which will be converted to an operational vehicle after completion of tests
- o EMD first flight: 2003
- o Production start: 2007
- o First delivery(including converted test vehicle): 2009
- o Initial Operational Capability (IOC): 2010
- o Peak annual production rate (3000-ton/5000-ton): 5/2
- o Production aircraft quantity (3000-ton/5000-ton): 85/25
- o Aircraft per squadron (3000-ton/5000-ton): 14/10
- o Total squadrons (3000-ton/5000-ton): 6/2
- o Pipeline spares & trainers (3000-ton/5000-ton): 10/3
- o Flying hours per vehicle per year: 350
- o Operational lifetime: 20 years
- o Operating locations: 2

5.2 CONFIGURATION-RELATED COST ASSUMPTIONS

Constrained by the limited definition and data for the two WIG concepts, the engine and avionics costs are assumed to be twice those for the C-5B, the closest size aircraft for which we have data. The engines are assumed to be similar to the PW-4084 high bypass ratio turbofan. The avionics suite is assumed to be similar to that on the C-5B aircraft, but with a much higher level of redundancy.

The airframes are postulated to be constructed with 80 percent metal and 20 percent composite materials. The labor costs vary with the mix of advanced materials; therefore, development of the advanced material adjustment factor begins with a breakdown, by weight and percentage, of the types and quantities of each material utilized. For example, historical data shows that use of composites requires 60 percent more engineering design labor than use of conventional metals, while use of advanced metals costs 10 percent more.

5.3 Flyaway Costs

The primary focus of the cost analysis is to establish a valid Unit Flyaway Cost (UFC) for each configuration, where UFC is the average procurement cost for the airframe (manufacturing material and labor for each of the structural components and subsystems), avionics, engines, and miscellaneous non-recurring startup costs and allowances for changes. Total procurement cost simply multiplies unit UFC by the production quantity and adds the costs for initial spares, technical data, publications, support equipment, and training equipment.

Figure 5.3-1 compares the summary elements of UFC for the two concepts. All costs are fully burdened (cost to the Government) and represent an average air vehicle cost for a buy of 25 5000-ton and 85 3000-ton WIGs in constant 1994 dollars. Due to its smaller size and greater learning curve benefit with a larger production run, the unit flyaway cost of the 3000-ton WIG is approximately 1.2 billion dollars lower than for the 5000-ton WIG.

If the unit flyaway costs are normalized to the payload capability of the vehicle, the benefits of the 5000-ton WIG are evident in its payload specific cost value of 1.6 million dollars per ton versus the 2.6 million dollars per ton for the 3000-ton WIG. For comparison with existing vehicles, the value for the C-5 is 1.6 million dollars per ton, and the value for a new LMSR is 0.012 million dollars per ton.

5.4 LIFE CYCLE COST

Life Cycle Cost (LCC) includes non-recurring cost, recurring cost, and operations and support (O&S) cost. Figure 5.4-1 compares the major life cycle cost elements for the 3000-ton and 5000-ton WIG concepts. The results show that the 5000-ton vehicle is a less

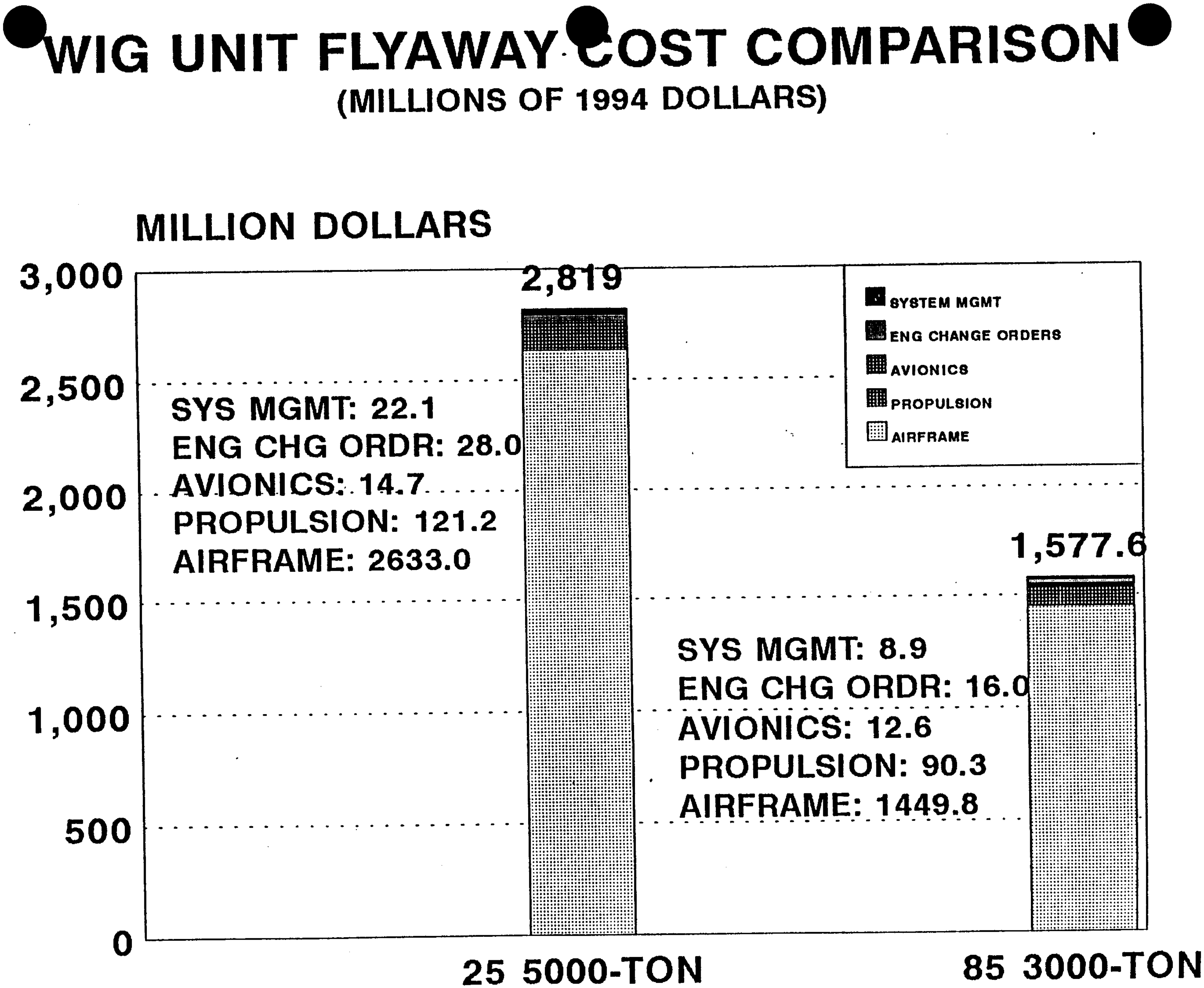


Figure 5.3-1. WIG Unit Flyaway Cost Comparison

WIG LIFE CYCLE COST COMPARISON

(BILLIONS OF 1994 DOLLARS)

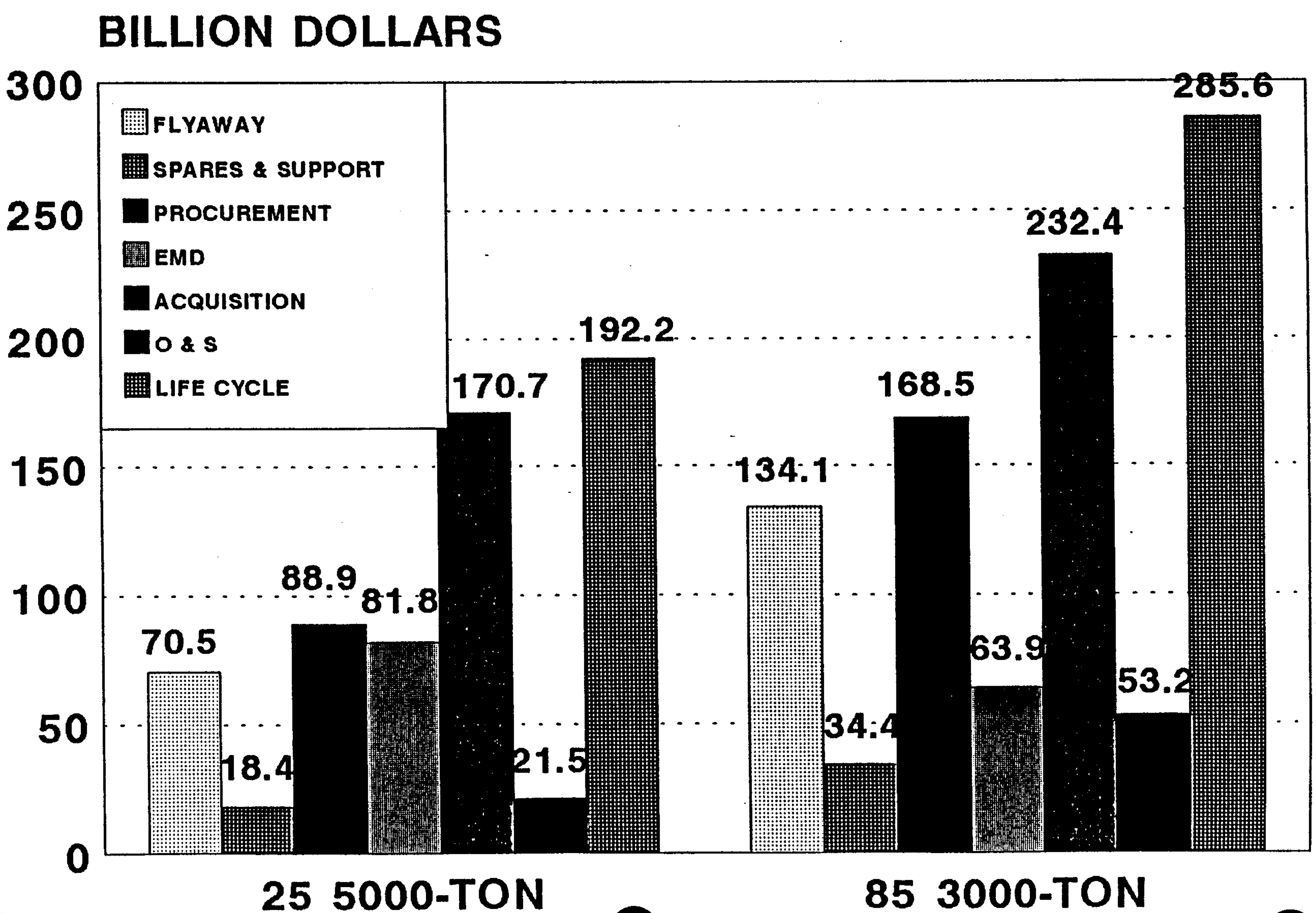


Figure 5.4-1. WIG Life Cycle Cost Comparison

expensive system than the 3000-ton vehicle over the life of the program.

The relatively higher non-recurring cost (i.e., EMD cost) of the 5000-ton vehicle is attributed to the greater amount of engineering that is required to design and develop the larger vehicle. The total procurement recurring cost of the 5000-ton vehicle is a considerably lower than for the smaller vehicle due to the large difference in the number of vehicles built.

The total O&S cost of the fleet of 5000-ton vehicles is approximately 27 billion dollars lower than for the fleet of smaller vehicles over the life of the program. This is indicative of the total manning and the number of operating vehicles. For this analysis, values for reliability, maintainability, utilization rate, and fuel burned per hour are approximately constant for both concepts. Detailed breakdowns of the O&S cost elements for the two WIG vehicles are included in Appendix C.

The LCC comparison of the two design concepts demonstrates the value of operating a larger vehicle over a smaller one, if and only if, the larger vehicle can be used to its full load capacity. The larger vehicle shows a saving of approximately 89 billion dollars over the life of the program. The major decrease in LCC is the result of 25 5000-ton vehicles being able to perform the same mission that requires 85 3000-ton vehicles.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The major conclusions and recommendations of this study are listed in Figures 6.0-1 and 6.0-2, respectively, and are discussed below.

6.1 CONCLUSIONS

WIGs offer the potential of being a unique mode of transportation that can deliver heavy Army units usually carried by ships but at aircraft speeds. Every item of equipment organic to a U.S. Army heavy mechanized division can be effectively loaded on both the 5000-ton and the 3000-ton WIG configurations. Doors for the cargo compartments are sufficiently high and wide to load/unload every item of equipment in the Army inventory.

Movement of two U.S. Army mechanized divisions from CONUS to SWA by sealift takes 27 days with a fleet of 12 LMSRs. To close these two divisions in the same time period with WIGs requires a fleet of 16 of the 5000-ton design or 52 of the 3000-ton design.

The 24-knot cruise speed capability of LMSRs precludes them from delivering the two divisions from CONUS to SWA in less than 27 days, regardless of their fleet size. With block speeds of 400 or 308 knots for the respective designs, WIGs can deliver the two division in considerably less time than 27 days by increasing the fleet size. Fleets of 20 5000-ton or 74 3000-ton WIGs close the two divisions in 21.5 days. To close the two divisions within 18 days (by the hypothesized start of hostilities in SWA), requires fleets of 25 5000-ton or 90 3000-ton WIGs.

The use of WIGs and existing airlift to support strategic deployment requirements are similar. When conflict scenarios demand the delivery of certain types of forces within time periods that cannot be satisfied by sealift, then airlift and WIGs are the answer. Once the sea lines of communications are established, then the use of WIGs and airlift are only economically justified for critical support roles.

When moving units or forces from their beddown locations to ports of embarkation, both WIGs and sealift suffer the same flexibility limits because they are constrained to water-based loading/unloading operations. Both must depend on the unit or force to transit from its beddown location to a port of embarkation, which adds substantially to the closure time. In contrast, airlift has greater flexibility because its loading/unloading operations are performed close to the unit's beddown location.

The projected unit flyaway cost per ton of cargo for the 5000-ton WIG of $1.6 million/ton is nearly identical to that for a C-5 but is considerably higher than the $0.006 million/ton for new LMSRs. For the 3000-ton WIG, the corresponding value is $2.57 million per ton.

CONCLUSIONS

- WIGS HAVE UNIQUE POTENTIAL TO CARRY HEAVY CARGO RELEGATED TO SHIPS AT AIRCRAFT SPEEDS
- TO MOVE TWO U.S. ARMY MECHANIZED DIVISIONS FROM CONUS TO SWA IN 27 DAYS REQUIRES:
  - 12 LMSR SHIPS (24 KNOTS CRUISE SPEED), OR
  - 16 5000-TON WIGS (400 KNOTS BLOCK SPEED), OR
  - 52 3000-TON WIGS (308 KNOTS BLOCK SPEED)
- TO MOVE THE TWO DIVISIONS FROM CONUS TO SWA QUICKER THAN THE 27 DAY MINIMUM BY SEALIFT REQUIRES:
  - 20 5000-TON OR 74 3000-TON WIGS TO CLOSE IN 21.5 DAYS
  - 25 5000-TON OR 90 3000-TON WIGS TO CLOSE IN 18 DAYS
- WIGS AND AIRLIFT ARE:
  - CRITICAL WHEN TIME IS LIMITED
  - NOT COMPETITIVE WITH SEALIFT IF TIME IS PLENTIFUL
- WIGS HAVE LESS FLEXIBILITY THAN AIRLIFT IN MOVING UNITS FROM HOME BASES BECAUSE OF WATER-BASED OPERATION RESTRICTIONS
- ON UNIT FLYAWAY COST PER TON OF CARGO CARRYING CAPABILITY
  - 5000-TON WIG SAME AS C-5 AT $1.6 M/TON
  - 5000-TON WIG MUCH HIGHER THAN LMSR AT $0.006 M/TON
  - 3000-TON WIG IS HIGHER AT $2.57 M/TON
- WIG CONCEPT HAS SEVERAL POTENTIAL COMMERCIAL APPLICATIONS BUT THEY NEED SMALLER VEHICLE THAN TWO POINT DESIGNS

Figure 6.0-1. Conclusions

RECOMMENDATIONS

- MORE IN-DEPTH DESIGN TO IMPROVE WEIGHT & COST CREDIBILITY
- DESIGN ATTENTION TO OPERATIONAL DETAILS
- DEVELOPMENT OF CONCEPT OF OPERATIONS DOCUMENT
- ANALYSIS OF COMMERCIAL APPLICATIONS AND OTHER MILITARY MISSIONS TO DERIVE DESIGN REQUIREMENTS

Figure 6.0-2. Recommendations

There are a number of potential commercial applications for a WIG concept but it probably needs to be much smaller than the two point designs addressed in this study.

6.2 RECOMMENDATIONS

More in-depth analyses are needed on the WIG designs to provide many of the missing operational features and to improve the weight and material estimates that are vital to the cost projections. For example, means for loading and unloading the 3000-ton design have not been addressed.

An operational concept document is needed that addresses all aspects of WIG utilization in wartime and peacetime conditions.

Detailed analyses are recommended that investigate a variety of airlift, military combat and non-combat, and commercial missions/applications to develop design requirements for an economically feasible WIG concept.

REFERENCES

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3. Randy Janssen; FAX on 3000-ton WIG; Air Force ASC/XREDT; 18 February 1994

4. Robert R. Vaughan; Telephone Conversation on Loading/Unloading; Aerocon Inc; 31 January 1994

5. Logistics Handbook for Strategic Mobility Planning, Military Traffic Management Command Transportation Engineering Agency (MTMCTEA), PAM 700-2, August 1989

APPENDIX A: UNIT EQUIPMENT LIST

HEAVY MECHANIZED DIVISION VEHICLE TYPES

	LIN	EMPTY WEIGHT	LOADED WEIGHT	L	W	H	DESCRIPTION	MODEL
VEH 1	A21633	3110	3110	408	74	106	AERIAL SCOUT HLCPTR	OH-58
VEH 2	A26271	2120	2120	147	73	69	AIR CONDITR TLR MTD	208V1
VEH 3	C10858	17864	29864	232	100	100	CARRIER CARGO: F/TRAC	M1015
VEH 4	C76335	40037	40537	258	117	104	CAVALRY FIGHTING VEH	M3
VEH 5	D02454X40931	20660	20660	315	99	86	TRK CGO 5T	M54A2
VEH 6	D10741	20131	20731	192	106	84	CARRIER 107MM MORT	M106A
VEH 7	D11049	17060	29060	223	104	77	CARRIER CARGO FTRAC	M548A
VEH 8	D11538	22415	25415	192	100	104	CARRIER COMD P FTRAC	M577A
VEH 9	J81750C76335	40037	40037	258	117	104	INFANTRY/CAV FIGHTING VEH	M2/M3
VEH 10	D78325	26300	26300	465	96	105	DATA PROCESSING SYS	AN/MY
VEH 11	E02807	2445	7445	169	94	41	CHASSIS TLR GEN	M200A
VEH 12	E32466	1270	1270	117	62	49	CLEANER STM PRES JET	125 P
VEH 13	E56578	108080	108080	289	144	128	CBT ENG VEH FTRAC	M728
VEH 14	E56896	22380	22380	189	100	104	COMBAT VEH IMP TOW	M901A
VEH 15	E70338	910	910	107	61	51	COMP RCP AIR TLR MTD	BM452
VEH 16	F39172	21200	21200	218	108	105	CRANE WHEEL MTD 3 TON	M63
VEH 17	F43077	13418	13418	204	102	90	CRANE WHL 7T W/BOOM	155-1
VEH 18	G34805	2080	2080	92	95	51	DOLLY SET LIFT	M720
VEH 19	G34815	3700	3700	126	96	52	DOLLY SET LIFT	M832
VEH 20	G53871	5710	5710	165	93	95	GEN SET TLR MTD	PU-76
VEH 21	H01855	16080	16080	371	96	132	ELCT SHOP STLRMTD L/P	AN/AS
VEH 22	H01857	14020	14020	396	96	132	ELCT SHOP STLR MTD	AN/AS
VEH 23	H28647	11311	11311	573	109	103	HELICOPTER ATTACK	AH-64
VEH 24	J35492	5310	5310	170	97	80	GEN SET DED TLR MTD	PU-40
VEH 25	J35629	7560	7560	170	97	88	GEN SET DED TLR MTD	PU-65
VEH 26	J35680	7728	7728	171	97	95	GEN SET DED TLR MTD	PU-70
VEH 27	J36383	6400	6400	171	97	83	GEN SET DED TLR MTD	PU-40
VEH 28	J40698	2230	2230	105	57	55	GEN ST GAS ENG	28V D
VEH 29	J41452	4500	4500	166	83	79	GEN SET GED TLR MTD	PU304
VEH 30	J41819	2780	2780	147	74	69	GEN SET GED TLR MTD	PU-37
VEH 31	J42100	4500	4500	175	85	65	GEN SET GED TLR MTD	PU-61
VEH 32	J46384	2180	2180	147	74	58	GEN SET GED TLR MTD	PU-61
VEH 33	J47480	3790	3790	176	84	65	GEN SET GED TLR MTD	PU-61
VEH 34	J47617	2840	2840	147	74	59	GEN SET GED TLR MTD	PU-62
VEH 35	J49055	825	825	49	40	39	GEN SET 7.5 KW WHLMTD	POLMC
VEH 36	J96694	24700	26200	190	100	106	GUN ARTILLERY SP 20MM	M163
VEH 37	K24931	600	600	81	40	38	HEATER DUCT WHL MTD	BT400
VEH 38	K30548	7085	7085	497	103	104	HELICOPTER UTILITY	EH-1H
VEH 39	K31042	1632	1632	212	78	86	HELICOPTER OBSN	OH-58
VEH 40	K31795	4992	5392	497	103	104	HELICOPTER UTILITY	UH-1H
VEH 41	K32293	12200	13600	496	117	105	HELICOPTER UTILITY	UH-60
VEH 42	K57667	48919	50419	355	125	110	HOWITZER MED SP 155MM	M109A
VEH 43	L44894	43941	43941	275	117	104	LAUNCHER ROCKET	MLRS
VEH 44	L76556	31090	31090	297	106	91	LOADER SCOOP TYPE WHL	950B
VEH 45	L85283	5300	5300	175	98	80	LUB SVC UNIT TLR MTD	90176
VEH 46	P11866	8910	8910	214	97	76	PNEU TL&COMP TLR MTD	250 C
VEH 47	P27819J36383	6400	6400	171	97	83	GEN SET DED TLR MTD	PU-406
VEH 48	P27819YA0045	6500	6500	171	94	83	POWER PLANT TLR MTD	PU-406
VEH 49	P27823J35629	7540	7540	170	97	84	GEN SET DED TLR MTD	PU-650
VEH 50	P27823YA0062	8038	8038	172	96	89	POWER PLANT TLR MTD	PU-650
VEH 51	P44627	3000	3000	90	50	60	POWER UNIT HCPTP MSVC	MEP-3
VEH 52	P97051	1825	1825	81	54	51	PUMP FLMB LIQ WHLMTD	GR04A
VEH 53	Q13633	22000	22000	269	100	130	RADAR ANT DR TRK MTD	VADS
VEH 54	Q15414	5790	5790	193	95	91	RADAR SET TLR MTD L/P	AN/MP
VEH 55	Q16046W95537	2880	2880	147	79	75	TLR CGO 3/4 TON	M101A1
VEH 56	Q16046X39940	10090	10090	284	86	102	TRK CGO 1-1/4 TON	M561
VEH 57	R11154	5100	5100	431	104	44	RAMP LOAD VEHICLE	MDS16
VEH 58	R39883W95400	1080	1080	109	62	44	TLR CGO 1/4 TON	M416
VEH 59	R39883X60833	3450	3450	132	64	71	TRK UTILITY 1/4 TON	M151A1
VEH 60	R40073	18120	18120	256	107	77	RECEIVING SET	AN/ML
VEH 61	R50544	49320	51320	254	124	115	RECOVERY VEH FTRAC	M578
VEH 62	R50681	107840	109840	323	144	124	RECOVERY VEH FTRAC	M88A1
VEH 63	R92996J46252	2100	2100	147	77	77	GEN SET GED TLRMTD	
VEH 64	R92996T59414	9350	9350	221	87	105	TRK CGO 5/4 T 4X4	M1028
VEH 65	S70027	14750	59750	358	96	95	STLR FLATBED 22 1/2 T	M871
VEH 66	S70243	17500	41500	597	97	72	STLR LOW BED WKR 12 T	M270A
VEH 67	S70517	16285	66285	416	115	72	STLR LOW BED 15-25 T	M172A
VEH 68	S70594	16918	96918	510	96	70	STLR LOW BED 40 TON	M870
VEH 69	S70661	31679	31679	515	120	108	STLR LOW BED 60 TON	M747
VEH 70	S72983	14250	14250	376	96	107	STLR TANK FSVC 5000 G	M131A
VEH 71	S74832	16580	16580	316	95	132	STLR VAN RPR PT STOR	M750
VEH 72	S75038	7180	19180	276	96	129	STLR VAN SHOP 6 TON	M146
VEH 73	S75175	15110	39110	346	98	142	STLR VAN SUPPLY 12TON	M129A
VEH 74	T00474	5360	8360	168	85	96	SHELTER SYS TLR MTD	M51
VEH 75	T05028	5220	6720	192	86	75	TRUCK UTIL 3/4 4X4	M1009

APPENDIX A CONTINUED

VEH 76	T10138	7290	7390	214	85	82	SHOP EQP CON/MAINT	SECM-
VEH 77	T10275	22520	22520	321	97	135	SHOP EQP ELEC REPAIR	SER-1
VEH 78	T13152	33030	33130	356	99	126	SHOP EQUIP ORG TRKMTD	SEORL
VEH 79	T13168	129000	129300	356	137	104	TANK COMBAT F TRACK	M1A1
VEH 80	T30377	2860	2860	112	79	76	TOOL OUTFIT TLR MTD	ADC 1
VEH 81	T39586	39420	59420	400	101	101	TRUCK CARGO TACT MLRS	M985
VEH 82	T39654	40220	60220	400	101	101	TRUCK CARGO MLRS 8X8	M985
VEH 83	T45465	8060	30060	266	96	50	TRAILER FLATBED 11 T	M989
VEH 84	T53498	5800	5900	221	83	79	TRK MAINT TEL 1-1/4T	M888
VEH 85	T58161	38165	38165	401	96	101	TRUCK TANK FUEL 8X8	M978
VEH 86	T59346	5920	8420	223	83	76	TRUCK CARGO 5/4 4X4	M1008
VEH 87	T59482	5900	8400	217	81	76	TRUCK CARGO 5/4T 4X4	M1008
VEH 88	T61035	38233	38333	370	99	124	TRUCK TRACTOR 8X6	M911
VEH 89	T63093	43180	43380	384	101	101	TRUCK WRECKER 8X8	M984
VEH 90	W00221	1905	1905	79	57	55	TEST STAND HYD WHLMTD	P/N A
VEH 91	W58486	2120	2120	146	75	69	TOOL OUTFIT TLRMTD(A)	PIONE
VEH 92	W76816	43220	43220	202	117	99	TRACTOR FTRAC LS DED	HO-16
VEH 93	W91074	15160	15160	348	90	102	TRACTOR WHL IND CCE	JD-41
VEH 94	W93995	860	860	117	72	57	TRAILER ACFT MAINT	AIRMO
VEH 95	W94030	2770	5770	149	95	57	TRAILER AMMO 1-1/2TON	M332
VEH 96	W95263	3050	10050	150	88	63	TRAILER CABLE REEL	M310
VEH 97	W95400	620	1120	108	61	43	TRAILER CARGO 1/4 TON	M416A
VEH 98	W95537	1350	2850	147	74	50	TRAILER CARGO 3/4 TON	M101A
VEH 99	W95811	2670	5670	166	83	55	TRAILER CARGO 1-1/2 T	M105A
VEH100	W96942	10000	42000	280	100	55	TRAILER F/BED TILT	16 TO
VEH101	W98825	2912	2912	162	81	81	TRAILER TANK WATER	M149A
VEH102	X23227	1200	1700	100	69	47	TRANSPORTER AIRMOBILE	74000
VEH103	X23277	27173	40173	377	135	116	TRANSPORTER BRDG FLTG	BRIDG
VEH104	X38592	6115	6315	224	80	104	TRK AMB 1-1/4 TON 4X4	M886
VEH105	X38961	7620	7820	226	84	65	TRUCK AMB 1-1/4 TON	M792
VEH106	X39432	4695	7195	219	80	74	TRK CGO 1-1/4 TON 4X4	M880
VEH107	X39441	4780	7280	219	80	74	TRK CGO 1-1/4 TON 4X4	M885
VEH108	X39447	4920	7420	219	82	74	TRK CGO 1-1/4 TON 4X4	M882
VEH109	X39450	4868	7368	219	80	74	TRK CGO 1-1/4 TON 4X4	M883
VEH110	X39453	4970	7470	219	80	74	TRK CGO 1-1/4 TON 4X4	M884
VEH111	X39440	7480	9980	232	86	68	TRUCK CARGO 1-1/4 TON	M561
VEH112	X40009	13180	18180	265	96	81	TRUCK CARGO 2-1/2 TON	M35A2
VEH113	X40077	13526	18526	265	98	82	TRK CGO D/S 2-1/2 TON	M35A2
VEH114	X40146	13570	18570	279	96	81	TRUCK CARGO 2-1/2 TON	M35A2
VEH115	X40283	14876	19876	329	96	81	TRK CGO 2-1/2T XLWB	M36A2
VEH116	X40794	22175	32175	311	97	94	TRK CGO D/S 5 TON	M923A
VEH117	X40831	22070	32070	311	97	94	TRK CGO 5 TON LWB	M924A
VEH118	X40968	23175	33175	332	97	94	TRK CGO 5 TON LWB	M926A
VEH119	X41105	25035	35035	386	97	94	TRK CGO 5 TON XLWB	M927A
VEH120	X41242	26135	36135	408	97	94	TRK CGO 5 TON XLWB	M928A
VEH121	X43708	25065	35065	273	97	94	TRUCK DUMP 5 TON	M929A
VEH122	X43845	26165	36165	295	97	94	TRUCK DUMP 5 TON	M930A
VEH123	X48914	23950	23950	186	103	93	TRK LIFT FRK RT 3 T	MLT6C
VEH124	X49051	33500	33500	203	107	98	TRK LIFT FRK RT 5 T	RTL-1
VEH125	X51585	9037	9037	97	46	83	TRK LIFT FRK GED 2 T	C500Y
VEH126	X57271	14600	14600	264	96	92	TRUCK TANK FS 2-1/2 T	M49A2
VEH127	X59326	21140	31140	265	97	94	TRUCK TRACTOR 5 TON	M931A
VEH128	X59463	22240	32240	286	97	94	TRUCK TRACTOR 5 TON	M932A
VEH129	X59600	33212	53212	290	115	111	TRUCK TRACTOR 10 TON	M123
VEH130	X60696	33874	43874	361	99	117	TRUCK TRACTOR WKR 5 T	M819
VEH131	Z94110	5200	7700	179	84	53	TRUCK 1/4 TON HMMUV	M1038
VEH132	X62237	29280	39280	363	98	142	TRUCK VAN EXP 5 T (A)	M934A
VEH133	X62271	31280	41280	376	98	142	TRUCK VAN EXP 5 T (A)	M935A
VEH134	X62340	15760	17760	265	100	130	TRUCK VAN SHOP 2-1/2T	M109A
VEH135	X62477	16170	16270	279	100	130	TRUCK VAN SHOP 2-1/2T	M109A
VEH136	X63299	38155	38255	362	97	118	TRUCK WRECKER 5 TON	M936A
VEH137	Y35486W95811	2670	2670	166	83	55	TLR CGO 1-1/2 T	M105A2
VEH138	Y35486YA0050	19480	19480	281	100	128	TRK VAN WTR PRFCN	2-1/2T
VEH139	Y48323	2510	2510	149	76	59	WELDING SHOP TLR MTD	NONE
VEH140	Z93546	5800	8300	221	87	76	TRK CAR 5/4 TON	XM102
VEH141	S70594	16918	16918	510	96	70	STLR LOW BED 40 TON	M870

APPENDIX B: TAC THUNDER MODEL DESCRIPTION

One of the most comprehensive and detailed campaign-level simulations available in the public domain today is Tac Thunder. This theater-level model has been developed by the Air Force Studies and Analysis, and is used extensively by DOD, industry, and foreign governments. Tac Thunder has a balance of detail and aggregation that allows the analyst to select the amount of fidelity desired for a particular study.

Tac Thunder is a two-sided, theater-level digital computer model designed to simulate conventional warfare. The model considers interactions of the air-land battle as well as highly detailed logistics and supply functions as shown in Figure B-1.

The air war models the mission planning sequence for explicit air missions and their execution. Intelligence is gathered and target lists are produced. Aircraft are allocated based on current resources, target priorities, and air allocation orders reflecting the theater commander's guidance. The aircraft allocation process assigns aircraft to targets and generates air tasking orders. A variety of air missions are tasked and flown. Figure B-2 is a graphical representation of air missions modeled in Tac Thunder. Air mission operations include taxi, takeoff and landing delays, servicing (refueling, rearming and multi-level maintenance), airbase damage/status (runways, POL(petroleum, oil, and lubricants), munitions, shelters, maintenance, and weather). These conditions dynamically interact with theater force operations to capture effects of the changing battlefield environment.

Ground combat simulation is based on the Army's Combat Effectiveness Model (CEM). The battlefield is composed of combat sectors to which the theater commander deploys combat units. Unit resolution is analyst-specified, typically at the brigade and division level. Battlefield description includes terrain, mobility, and road/rail/sea route information. Ground combat units are made up of user-defined equipment such as tanks, infantry fighting vehicles (IFV), artillery pieces, attack helicopters, multiple-launch rocket systems (MLRS), etc.. Ground forces are engaged in both ground-to-ground and air-to-ground attacks. Attrition is calculated using the Attrition Calibration (ATCAL) model developed by the U.S. Army Concepts Analysis Agency (CAA). Movement of the Forward Line of Troops (FLOT) is based on combat operations, logistics, and communications.

Requirements are generated for resupply of equipment, ammunition, POL, dry bulk, and water. Critical resources, such as Laser Guided Munitions or M1A1 tanks, may be discretely modeled and tracked during the simulation. Supply depots and supply convoys are targets for attack. Road, rail, and sea transportation networks, as well as transshipping centers, are modeled and vulnerable to attack. The movement of units and supplies is limited by the condition of the transportation system and available transport assets. Constrained availability and issue capacities are considered, and unit performance is degraded by lack of

TAC THUNDER

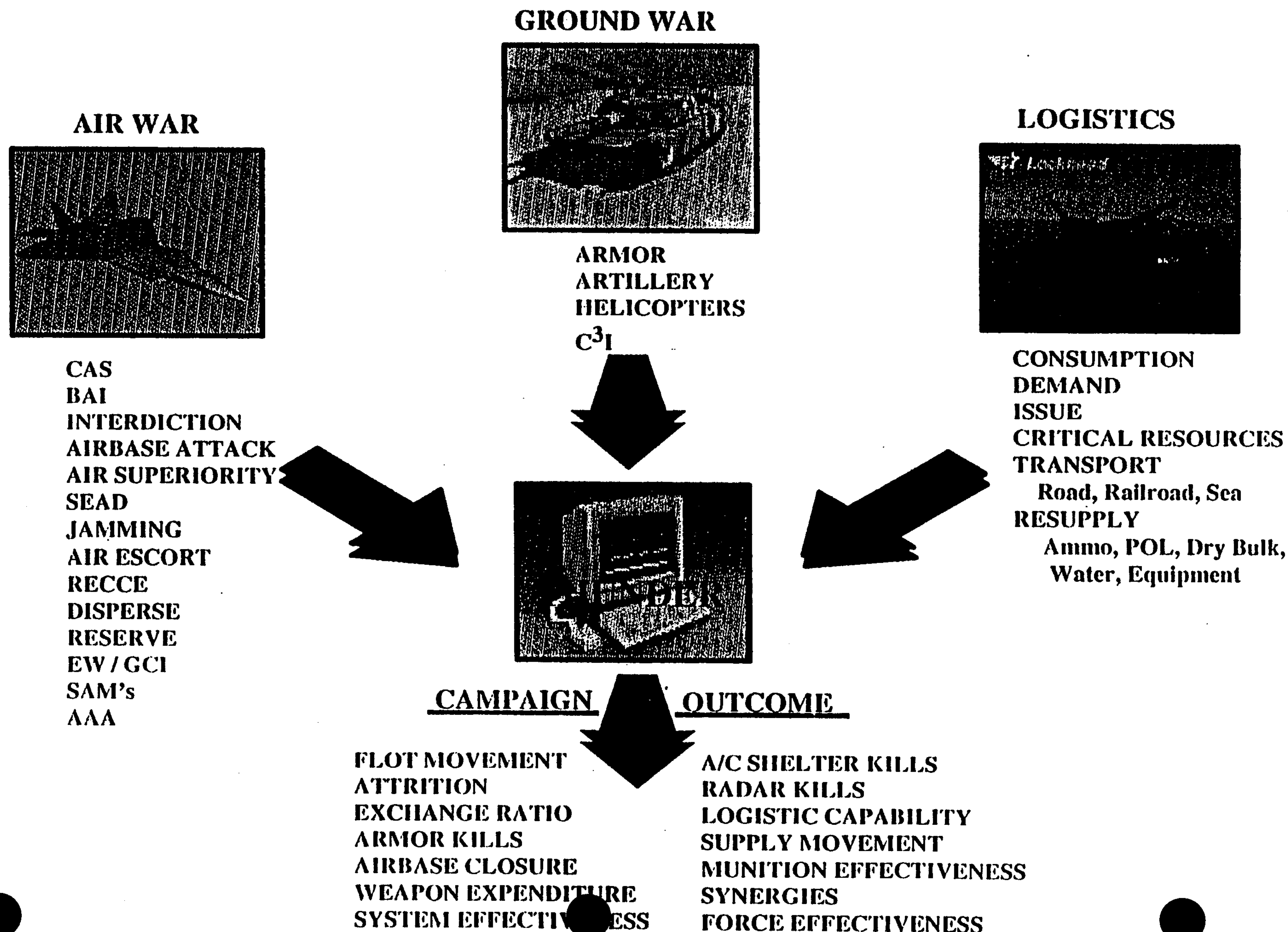


Figure B-1. Tac Thunder Model Features

AIR MISSIONS

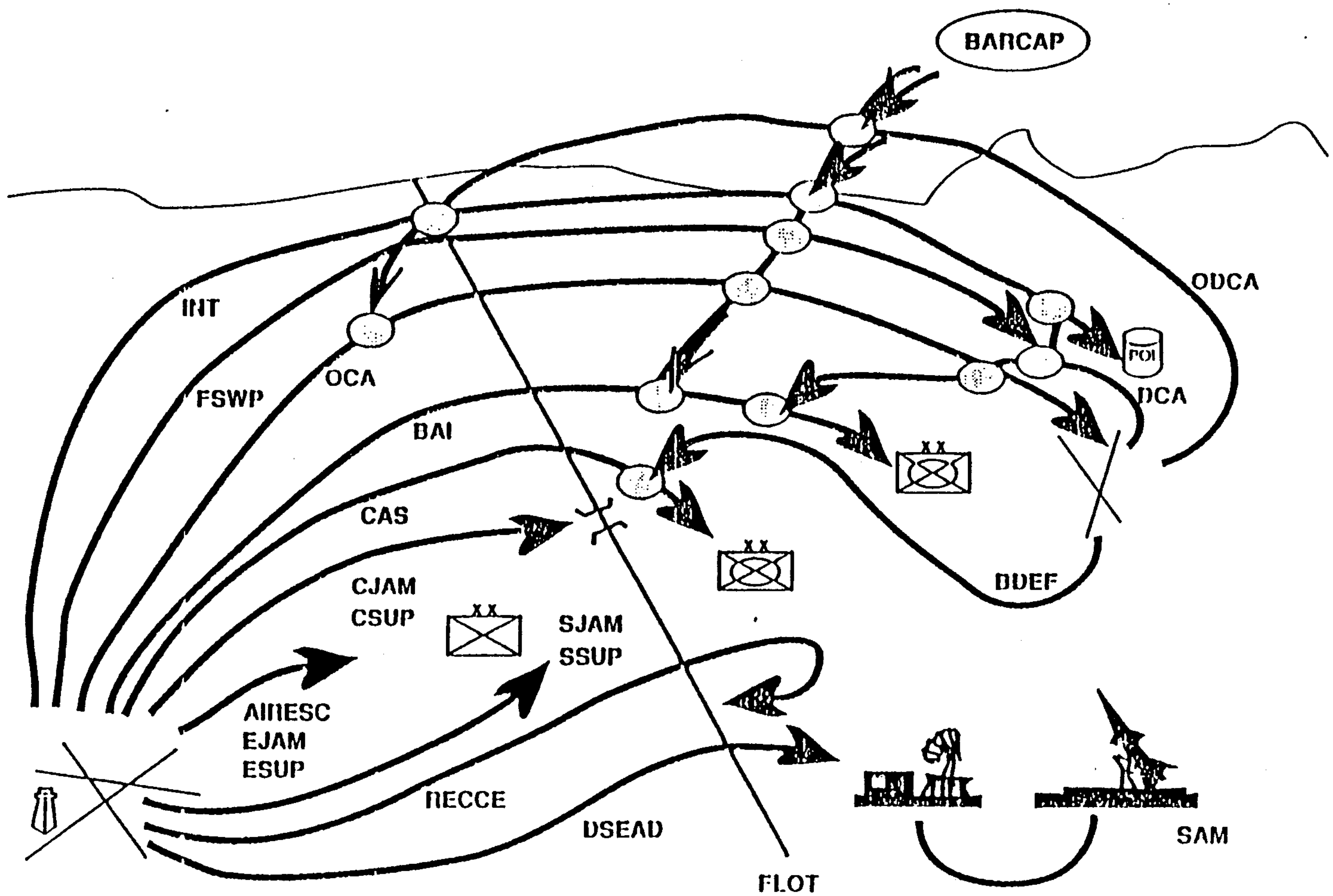


Figure B-2. Tac Thunder Air Missions

supplies. This level of detail allows for study of logistical problems such as combat unit deployment and sustainability in the dynamics of a theater-level conflict.

APPENDIX C: LOCKHEED LIFE CYCLE COST MODEL DESCRIPTION

Total acquisition costs, both Engineering and Manufacturing Development (EMD) and procurement, were estimated for the two WIG design concepts using Lockheed's Life Cycle Cost Model (LLCCM). Figure C.1 depicts the subroutine areas in the LLCCM and shows how they interact to estimate total life cycle cost which includes Operating and Support (O&S) costs. This model is based on a series of parametric regression equations called Cost Estimating Relationships (CERs) developed by Lockheed using historical data from numerous in-house aircraft programs. The CERs are driven by independent variables describing such things as the vehicle's weight, speed, thrust, complexity, and state-of-the-art. For major cost items like avionics equipment and engines, supplier's data are usually input directly.

A primary cost driver in LLCCM, as in many costing models, is the weight of the system. It has been shown many times that the cost of an air vehicle is directly proportional to its weight. The majority of the CERs used in the LLCCM model have weights as their primary independent variables. A material mix factor is used in the LLCCM to adjust manufacturing labor and material dollars to account for new materials and processes being incorporated into future designs.

An important aspect of the CER equations used in the LLCCM to estimate EMD is the use of state-of-the-art (SOA) and complexity factors. These factors describe the level of effort and/or familiarity a company should encounter in designing a new vehicle relative to previous aircraft and/or company experience. SOA is an interpretive factor which ranges in value of one to three. A value of one is for a level of technology that has been performed many times before by the industry. A normal new program with moderate technology advancement has a SOA value of two. An SOA of three represents a program with maximum innovation, but without a breakthrough in technology.

Complexity factor values are unique to each configuration and are not lowered because of a prior model version. These factors, derived from the database aircraft, are used to introduce cost variances in the historical costs that are not accounted for by other variables such as SOA.

Detailed O&S cost data are provided in Figures C-2 and C-3 for the 3000 and 5000 ton WIGs, respectively. Cost values are listed for each of the eight major contributing areas for O&S cost. The three sets of cost values listed are for: 20 years of operation of the full fleet, annual squadron operation, and 20 years of operation of a single vehicle.

REQUIRED INPUTS TO PARAMETRIC COST MODEL

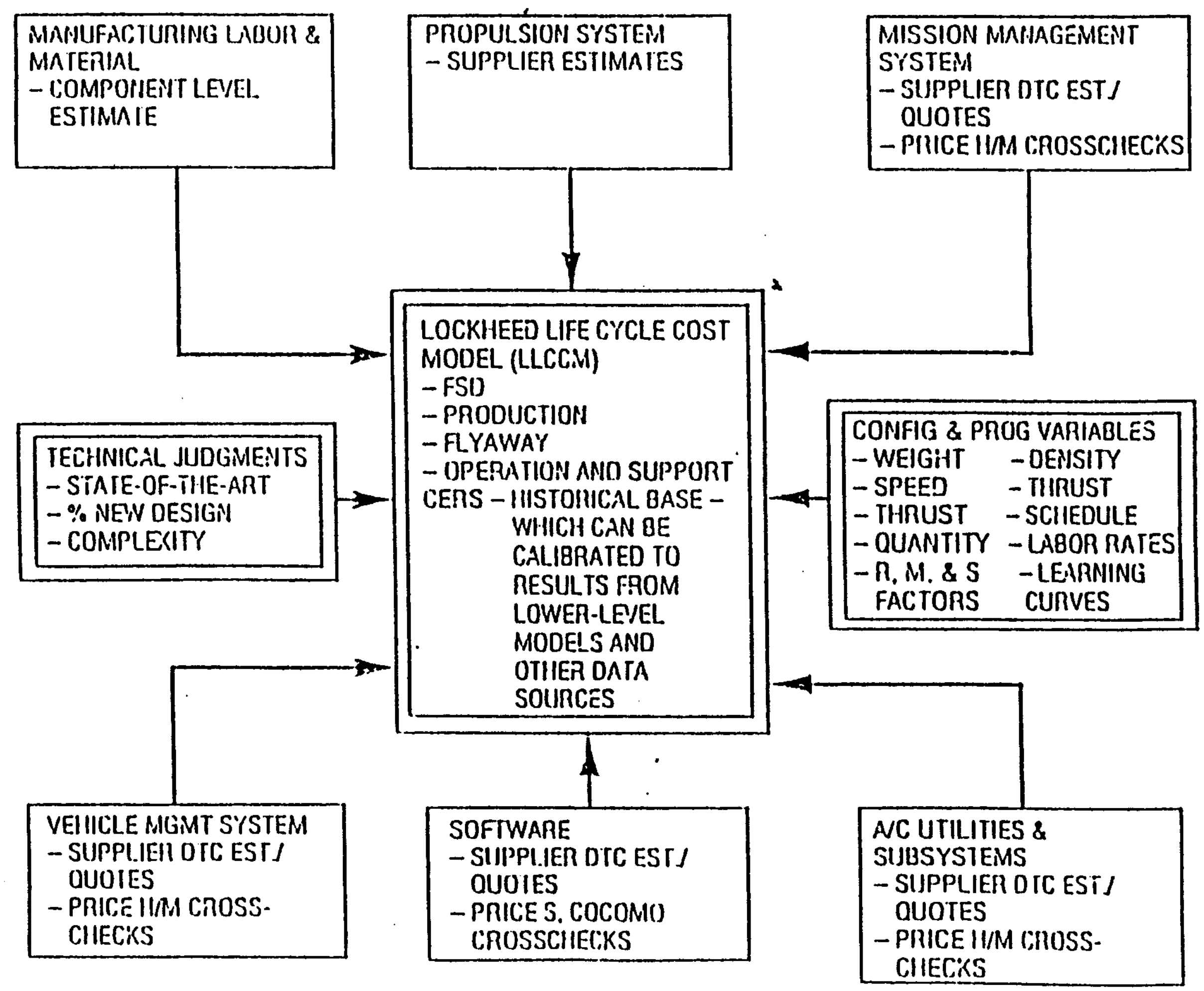


Figure C-1. Required Inputs to Parametric LLCCM

O & S Cost Summary 1994 $M	FORCE 20-YR O&S ($M)	ANNUAL SQUADRON O&S ($M)	UNIT 20-YR O&S ($M)
UNIT MISSION PERSONNEL	$20,019.3	$189.37	$270.530
Aircrew	$1,839.8	$17.40	$24.862
Aircraft Maintenance	$16,713.1	$158.10	$225.852
Other	$1,466.4	$13.87	$19.816
Unit Staff	$314.6	$2.98	$4.252
Security	$116.1	$1.10	$1.569
Other	$1,035.6	$9.80	$13.995
UNIT LEVEL CONSUMPTION	$10,265.0	$97.10	$138.716
Aviation Fuel	$9,088.1	$85.97	$122.812
Aircraft Maint. Material	$1,176.9	$11.13	$15.904
Training Ordnance	$0.0	$0.00	$0.000
DEPOT LEVEL MAINTENANCE	$5,560.7	$52.60	$75.145
SUSTAINING INVESTMENT	$5,866.0	$55.49	$79.270
Reparable Spares	$2,714.3	$25.68	$36.680
Support Equipment	$277.6	$2.63	$3.751
Modification Kits	$2,874.1	$27.19	$38.839
Other Recurring Investment	$0.0	$0.00	$0.000
INSTALLATION SPT. PERSONNEL PAY	$2,951.3	$27.92	$39.882
Base Ops/Comm Spt. (BOS)	$2,414.4	$22.84	$32.627
Real Property Maintenance	$208.4	$1.97	$2.816
Medical	$328.5	$3.11	$4.440
INDIRECT PERSONNEL SUPPORT	$6,430.5	$60.83	$86.898
Misc. O&M Support	$5,157.0	$48.78	$69.689
Medical Non-Pay Support	$281.7	$2.67	$3.807
Permanent Change of Station	$991.7	$9.38	$13.401
DEPOT-NON MAINTENANCE	$0.0	$0.00	$0.000
General Depot Support	$0.0	$0.00	$0.000
Second Destination Trans.	$0.0	$0.00	$0.000
PERSONNEL ACQUISITION & TRAINING	$2,139.6	$20.24	$28.913
Acquisition (Incl. Basic Tng.)	$774.7	$7.33	$10.469
Individual Training	$1,364.8	$12.91	$18.444
Pilot Training	$422.7	$4.00	$5.713
Non Pilot Aircrew	$80.8	$0.76	$1.092
Navigator Tng.	$17.2	$0.16	$0.233
Enlisted Tng.	$63.6	$0.60	$0.859
Specialty Training	$861.3	$8.15	$11.639
Officer	$25.4	$0.24	$0.343
Enlisted	$835.9	$7.91	$11.295
GRAND TOTAL	$53,232.3	$503.55	$719.355

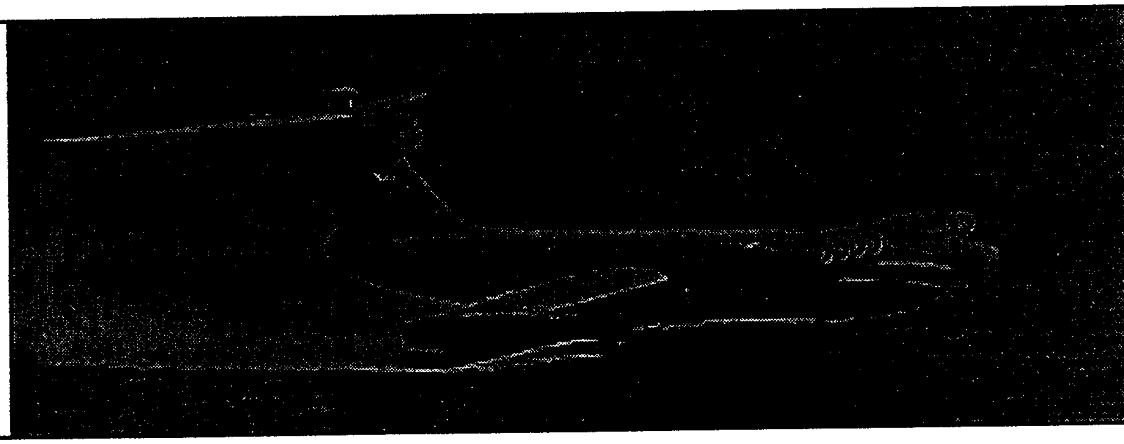
Figure C-2. O&S Cost Breakdown for 3000-ton WIG

O & S Cost Summary 1994 $M	FORCE 20-YR O&S ($M)	ANNUAL SQUADRON O&S ($M)	UNIT 20-YR O&S ($M)
UNIT MISSION PERSONNEL	$8,841.6	$221.04	$442.081
Aircrew	$495.9	$12.40	$24.795
Aircraft Maintenance	$7,587.6	$189.69	$379.381
Other	$758.1	$18.95	$37.906
Unit Staff	$142.2	$3.56	$7.112
Security	$53.3	$1.33	$2.663
Other	$562.6	$14.07	$28.131
UNIT LEVEL CONSUMPTION	$2,919.2	$72.98	$145.960
Aviation Fuel	$2,442.1	$61.05	$122.104
Aircraft Maint. Material	$477.1	$11.93	$23.856
Training Ordnance	$0.0	$0.00	$0.000
DEPOT LEVEL MAINTENANCE	$2,254.4	$56.36	$112.718
SUSTAINING INVESTMENT	$2,461.1	$61.53	$123.054
Reparable Spares	$1,100.4	$27.51	$55.020
Support Equipment	$112.5	$2.81	$5.626
Modification Kits	$1,248.2	$31.20	$62.408
Other Recurring Investment	$0.0	$0.00	$0.000
INSTALLATION SPT. PERSONNEL PAY	$1,312.0	$32.80	$65.602
Base Ops/Comm Spt. (BOS)	$1,072.2	$26.81	$53.611
Real Property Maintenance	$94.0	$2.35	$4.7[illegible]
Medical	$145.8	$3.64	$7.2[illegible]
INDIRECT PERSONNEL SUPPORT	$2,859.9	$71.50	$142.996
Misc. O&M Support	$2,294.0	$57.35	$114.698
Medical Non-Pay Support	$125.8	$3.14	$6.290
Permanent Change of Station	$440.2	$11.00	$22.008
DEPOT-NON MAINTENANCE	$0.0	$0.00	$0.000
General Depot Support	$0.0	$0.00	$0.000
Second Destination Trans.	$0.0	$0.00	$0.000
PERSONNEL ACQUISITION & TRAINING	$869.7	$21.74	$43.486
Acquisition (Incl. Basic Tng.)	$339.9	$8.50	$16.996
Individual Training	$529.8	$13.25	$26.490
Pilot Training	$114.3	$2.86	$5.713
Non Pilot Aircrew	$21.8	$0.55	$1.092
Navigator Tng.	$4.7	$0.12	$0.233
Enlisted Tng.	$17.2	$0.43	$0.859
Specialty Training	$393.7	$9.84	$19.685
Officer	$11.5	$0.29	$0.576
Enlisted	$382.2	$9.55	$19.110
GRAND TOTAL	$21,517.9	$537.95	$1,075.897

Figure C-3. O&S Cost Breakdown for 5000-ton WIG

BDM FEDERAL
A BDM International Company

WING-IN-GROUND (WIG) EFFECT VEHICLE MISSION ANALYSIS:
METRIC COMBAT SIMULATIONS



Kevin B. Wilshere
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WING-IN-GROUND (WIG)

EFFECT VEHICLE MISSION ANALYSIS:

METRIC COMBAT SIMULATIONS

A. ANALYTICAL OBJECTIVES

In assessing potential military applications for Wing-in-Ground (WIG) effect vehicles, it is important to expand the analysis beyond technical feasibility assessments. It is essential to also measure the impact mission-capable WIGs could have on combat outcomes. The emphasis of this analysis is to provide preliminary answers to some of the "so what" questions surrounding WIG performance; i.e., what return on investment in terms of improved U.S. combat capabilities may be realized by developing and employing WIGs. Consequently, BDM has incorporated several potential WIG combat missions into the simulation of a broader Southwest Asia (SWA) scenario involving U.S. early entry forces. A base case scenario (non-WIG) is compared with three excursions in which WIG technology is simulated to perform various combat and lift missions. The simulation results support assessments of the impact that WIG technology could have on disrupting threat offensive operations and preserving U.S. forces in a single scenario, as well as inferences about other possible military roles.

This analysis is intended to provide a basis for continuing assessments of potentially valuable military missions for WIG technology. The analysis is not comprehensive with respect to all potential missions, but it does provide insights into the operational significance of several WIG combat and lift roles. While the selected missions emphasize the speed, range, endurance, and capacity of WIG applications, further study will be needed to determine whether other existing or projected combat systems would be capable of performing the same missions more effectively and/or at lower cost. In addition, the application of WIG technology in other theater scenarios and combat intensities is vital before final conclusions can be drawn concerning the potential operational utility of WIG craft.

B. THE METRIC MODEL

The METRIC simulation was chosen to conduct WIG operational analysis. METRIC is a key component of the FOCUS family of tools which support a wide range of operational analyses at varying levels of resolution (see ***Figure 1***). FOCUS includes worldwide order of battle and equipment data bases; simulation models for mobilization, transportation, and combat analysis; a geographic information system (GIS); and graphics workstations.

The METRIC model is an advanced joint warfare simulation which incorporates a robust representation of command, control, communications, computers and intelligence (C4I) architectures to support analysis of "force multiplier" technologies and employment concepts. As depicted in ***Figure 2***, METRIC is used to model joint warfare, including combat and non-combat missions (such as logistics). METRIC's modules include artificial intelligence (AI) routines to automatically provide dynamic battle management within the simulation, or the model can be run with humans-in-the-loop (see ***Figure 3***). In support of the WIG analysis, most U.S. and threat tactical operations were run under computer control. WIG employment concepts were input by players and executed by existing AI routines based on perceptions of tactical situations.

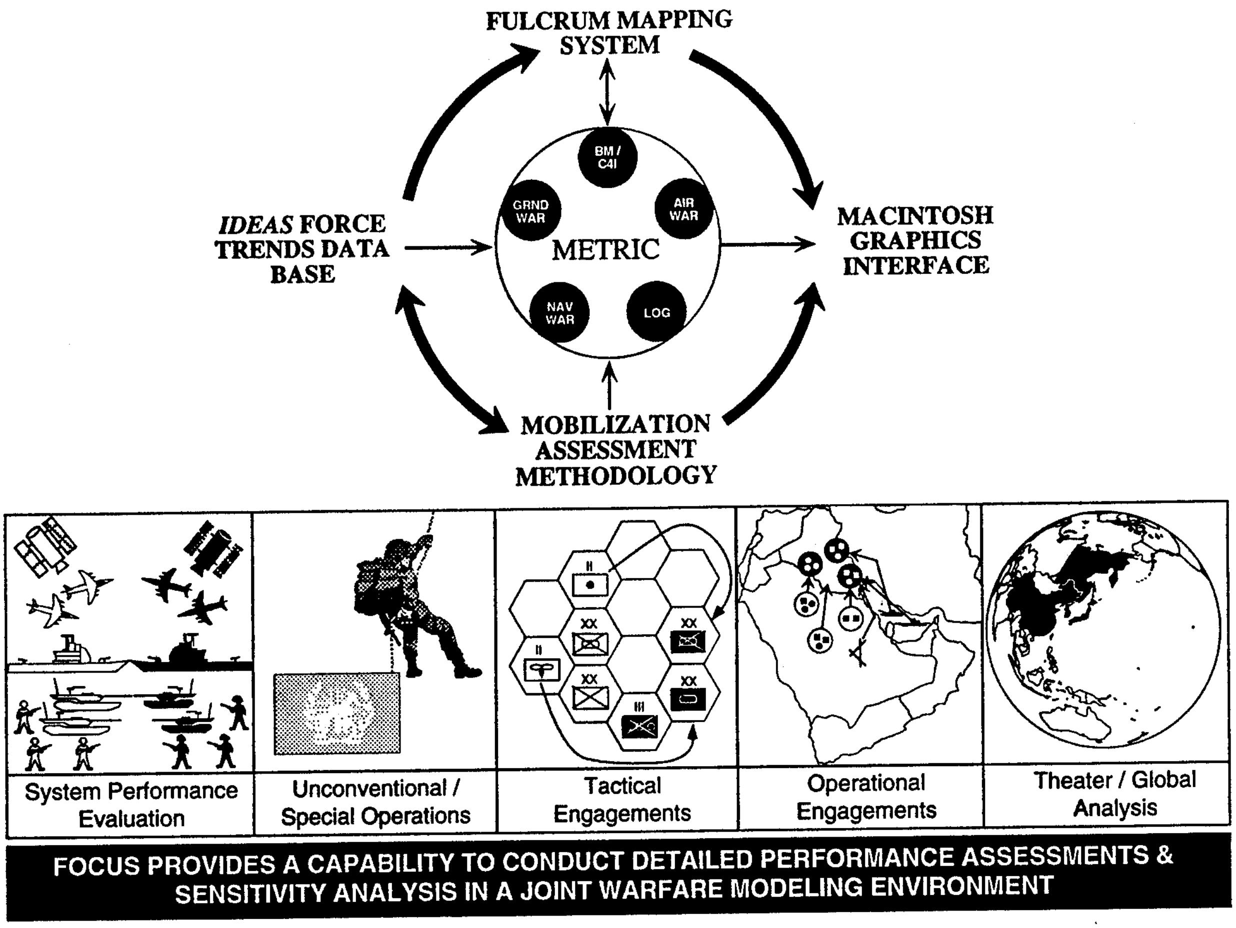


Figure 1. FOCUS Model Family.

Outputs from METRIC include combat results by side, by unit, and by system (both as shooter and as target); communications statistics by radio, by network, and by sender or receiver; intelligence reports by side, by unit, and by sensor; map overlays depicting the progress of combat in either real-time or replay mode; and a variety of other statistics and reports describing system performance and engagement results. Several of these report types are used to support this analysis.

C. SCENARIO OVERVIEW

To support the goal of focusing on modeling and analysis rather than scenario development, an existing scenario from another recent ARPA study was chosen for the WIG analysis. In this scenario, a light U.S. early entry force on the ground near Al Jubayl, Saudi Arabia conducts joint operations with U.S. air and naval forces against a mechanized Iraqi incursion into Saudi Arabia. The breakthrough force employs two avenues of advance, one along the coast and the other approximately 100 kilometers inland, in a north-south movement. The Iraqi objective is to overrun the U.S. positions and capture the reinforcement and staging areas at Al Jubayl and Dhahran. The scenario involves attacks by Iraqi forces on U.S., coalition and indigenous Saudi units both along the Saudi Arabian Persian Gulf coastline and inland against King Khalid Military City (see *Figure 4*). This analysis focuses on a pre-supposed, corps-sized Iraqi breakthrough force advancing through Kuwait and into Saudi Arabia. Other threat and friendly activities unrelated to the breakthrough are not depicted (although some diversion of total available assets is assumed).

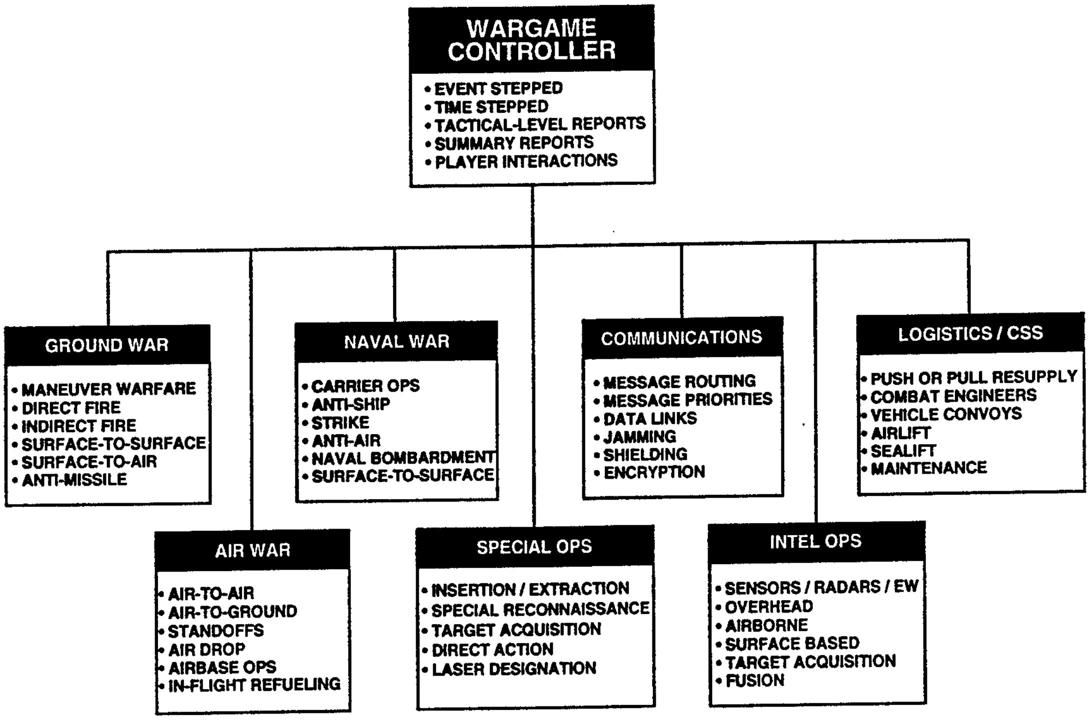


Figure 2. METRIC Gameset.

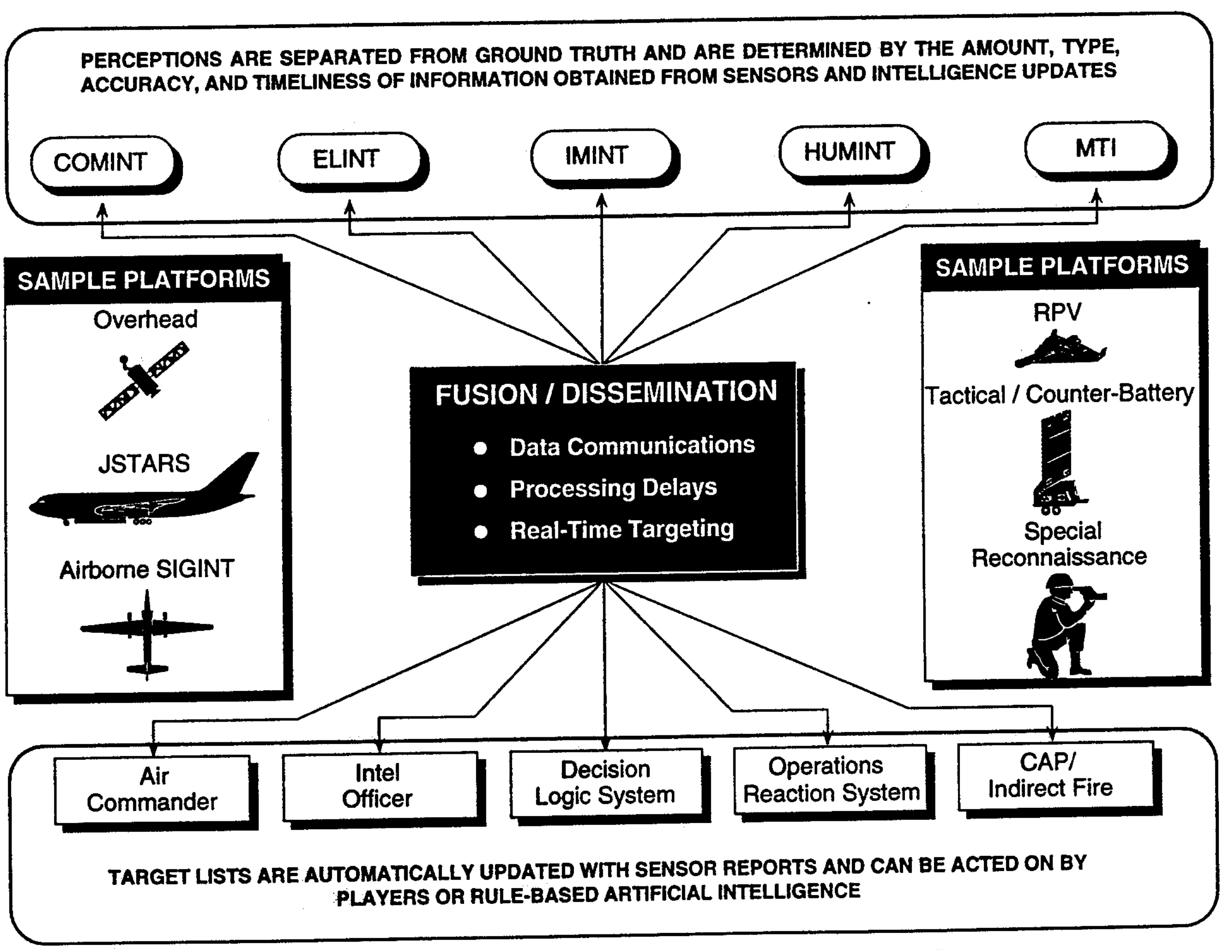


Figure 3. Automated Exploitation of Intelligence in METRIC.

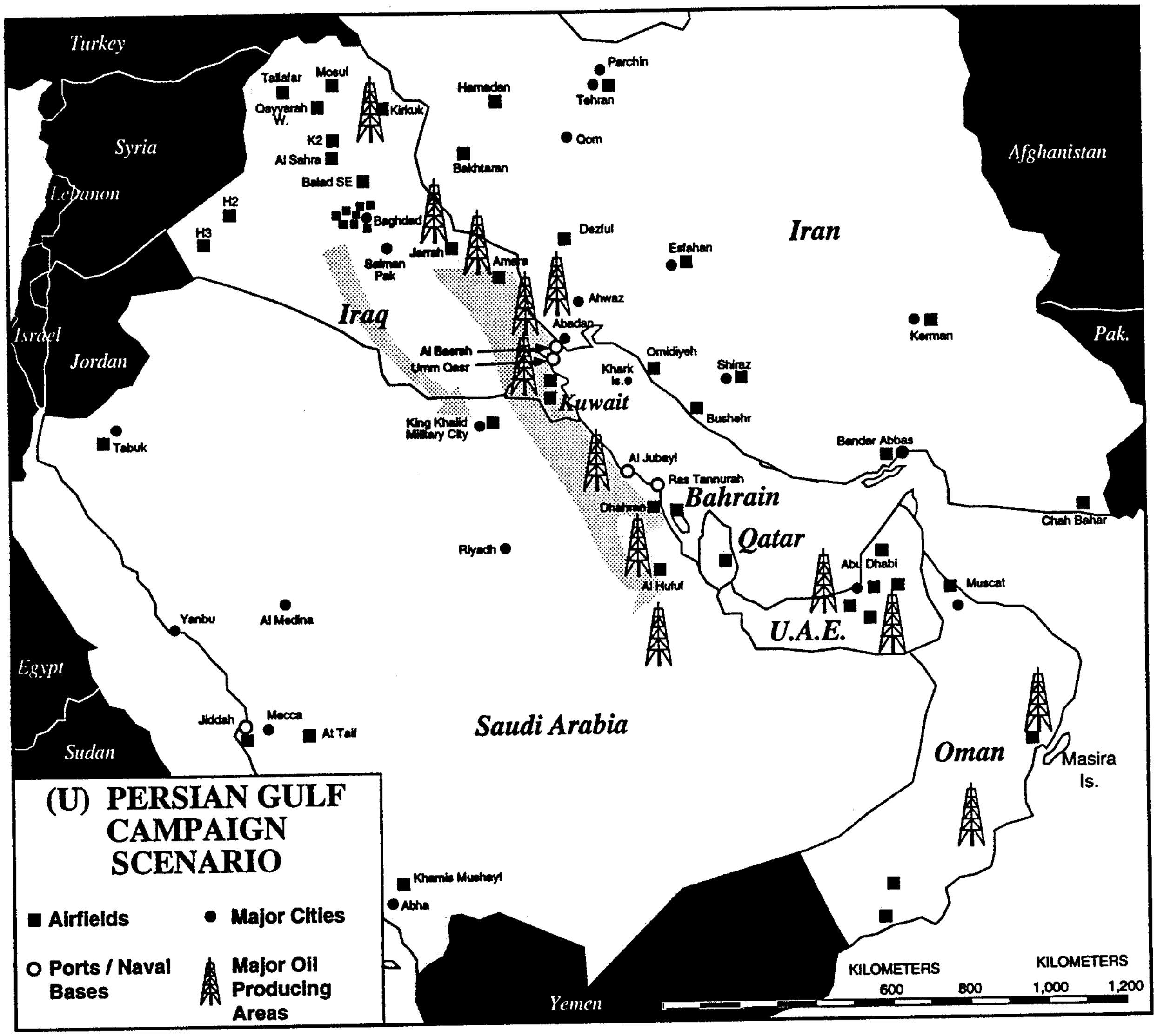


Figure 4. Scenario Overview.

The defending U.S. force consists primarily of two battalions of the 82nd Airborne Division supported by other elements of the XVIII Airborne Corps; elements of a Marine Expeditionary Brigade (MEB), including an armored battalion and a mechanized company; a carrier battle group (CVBG) in the Persian Gulf; and Air Force units based at Riyadh and Dhahran. The primary lethal assets of the light U.S. ground forces are 18 AH-64D Apache/Longbow helicopters, 18 AH-1 Cobra helicopters, and 9 multiple launch rocket systems (MLRS) using ATACMs Block I and II rounds. Fixed wing aircraft devoted to stopping the breakthrough include 48 F-15Es, 10 A-6s, and 24 F/A-18s. Air launched standoff munitions include Tri-Service Stand-Off Attack Missile (TSSAM), Joint Stand-Off Weapon (JSOW), High-Speed Anti-Radiation Missile Block IV (HARM IV), Stand-Off Land Attack Missile (SLAM) and Hellfire/Longbow. Riyadh and Dhahran are defended by Patriot and theater high-altitude air defense (THAAD) anti-missile systems, as well as point air defense assets. U.S. reconnaissance, surveillance and target acquisition (RSTA) architecture includes AWACS, JSTARS, U2-R with ASARS, Rivet Joint, and overhead satellites.

The threat forces advancing along the coast consist of one heavy (double-size) armored division equipped with T-72 main battle tanks and a variety of maneuver and support assets. Advancing approximately 100 kms inland, is a second similarly equipped force consisting of an armored and a mechanized division. These ground forces are supported by 1,000 kilometer ballistic missiles fired from fixed sites in southern Iraq and mobile SCUD launchers; 45 MiG-29 Fulcrum air defense aircraft; 45 SU-22 Fitter ground attack aircraft; 40 Mi-25 Hind-D ground attack helicopters; and long-range, heavy artillery. The Hinds are forward-deployed to a Forward Area Rearmament and Refueling Point (FARP) outside the range of U.S. MLRS/ATACMs; likewise, the ballistic missile launchers cannot be reached by any ground systems. Threat air defense systems include SA-10s, SA-15s, and various hand-held SAMs and air defense artillery. The threat RSTA architecture includes a Mainstay-type AWACs, Gazelle reconnaissance helicopters, and tactical assets. This order of battle was deliberately modernized to present the U.S. force with a robust threat of the type anticipated in many Third World countries after the turn of the century.

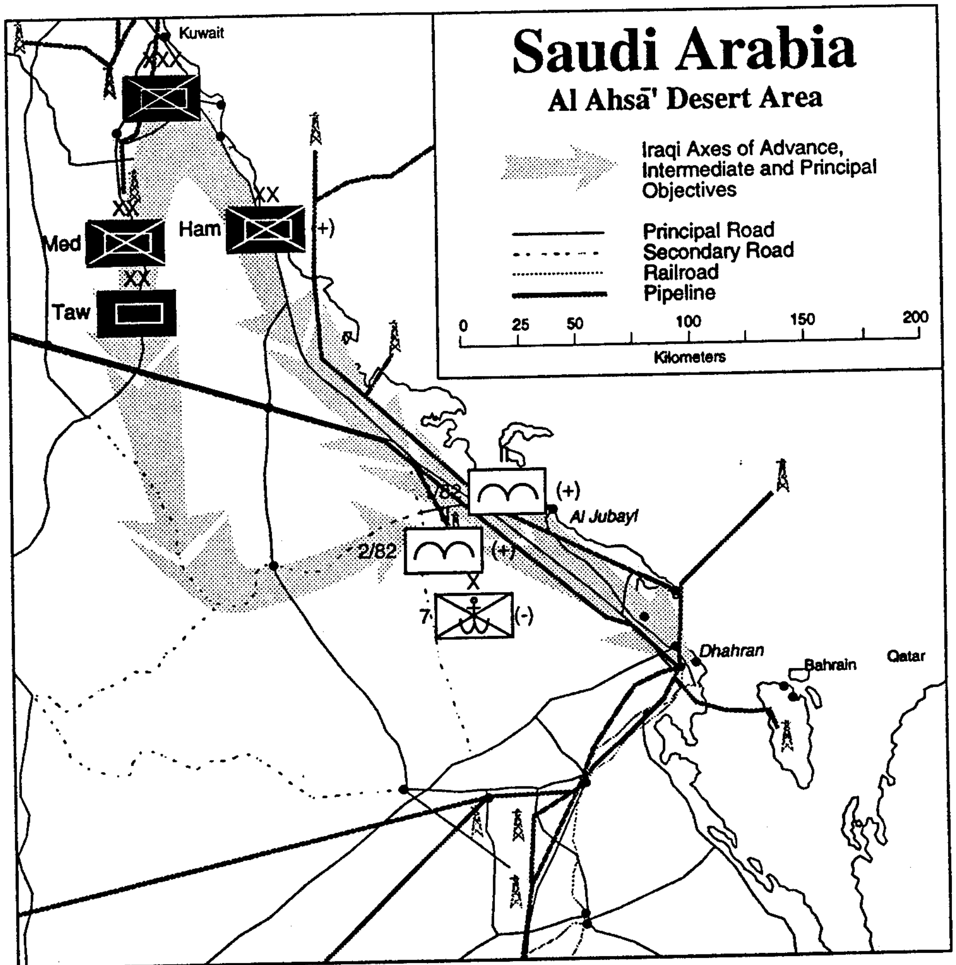
Deployment of major ground units is depicted on ***Figure 5***. As the threat units begin to advance southward toward the U.S. ground positions, U.S. fixed wing aircraft begin interdiction strikes (although they are hampered by a low cloud ceiling and the limited number of ground attack aircraft available). The U.S. force supplements fixed wing operations with attack helicopters, and ATACMs as the threat units move within range. Meanwhile, Iraq targets U.S. air bases in Saudi Arabia and ground forces with combinations of fixed wing aircraft and ballistic missile attacks. Early on Day 1, Hinds also begin ground attack missions, principally against MLRS units and the helicopter base near Al Jubayl. The U.S. responds to the threat helicopter attacks with Apache strikes, but not until the night of Day 1/Day 2 when the mission can be accomplished under cover of darkness. Throughout Days 2 and 3, the air war continues with targeting priorities modified by each sides' situation awareness of battlefield conditions. Threat ground units continue to advance toward contact with the defending U.S. force by late in Day 3.

D. DESCRIPTION OF SIMULATED WIG MISSIONS

1. Summary

As a result of the initial threat advantage in combat power, the U.S. strategy is to employ long-range systems to interdict ground forces and neutralize the significant enemy direct fire advantage. Consequently, one of the best potential combat applications identified for WIGs was interdiction of threat forces beyond the effective range of U.S. attack helicopters and ATACMs. Other opportunities were identified, as well, for the use of WIGs in the northern Persian Gulf against targets requiring extreme forward deployments.

After evaluating a broad range of possible WIG combat missions, four combat applications were selected for analysis in the excursion case: air defense, navalized variants of ATACMS (henceforth NTACMs), theater missile defense (TMD), and sea-landed cruise missiles (SLCMs). The four applications were designed such that the WIG's range, mobility, and endurance would be important factors to successful accomplishment of the missions. A total of six combat WIGs were deployed to the Persian Gulf. Five WIGs were equipped with vertical launch systems (VLS) capable of accommodating any of the missiles associated with the chosen missions. Throughout the scenario, two WIGs were dedicated to NTACMs missions and one WIG each to the air defense, TMD and SLCM roles. The sixth WIG played a combat support role and was equipped with a three-dimensional, phased array radar to provide aircraft and missile acquisition and tracking data to the other WIGs and ground stations at Riyadh and Dhahran.



Threat concept of operations based on combined arms corps moving south in two axes with coordinated air and missile support

- Continuous air support throughout three day offensive
  - Air cover provided by MiG-29 aircraft based in Iraq
  - Early fighter-bomber attacks to destroy / suppress MLRS units
  - Close air support available from helicopter forward area refueling and rearming point (FARP) established along inland road march

- Surface-to-surface missile strikes on U.S. forces from launchers in Iraq and mobile SCUDs
  - Small number of 1,000 km missiles launched at U.S. air facilities
  - SCUDs target long-range U.S. artillery and ground forces

- Long-range artillery suppression and counter-battery fires prior to initiating close combat

- Overwhelming massed attacks on U.S. defensive positions

Figure 5. Threat Operational Concepts.

BDM also assessed the potential impact on combat outcomes of two WIG lift scenarios in which additional assets were made available to the U.S. ground forces. Similar to the combat mission selection process, a variety of lift possibilities were considered, including deployment of: a heavy corps; an armored cavalry regiment (ACR); and, small (below battalion-size) tailored force packages designed to address specific U.S. in-theater force deficiencies. As will be discussed later in this report, the lift modeling and analysis focused on the lower end of the spectrum of unit deployment possibilities. The purpose of the lift scenario analysis was to support an evaluation of the operational impact WIG technology could have by providing a high speed heavy lift capability to rapidly supplement the other forces in the scenario.

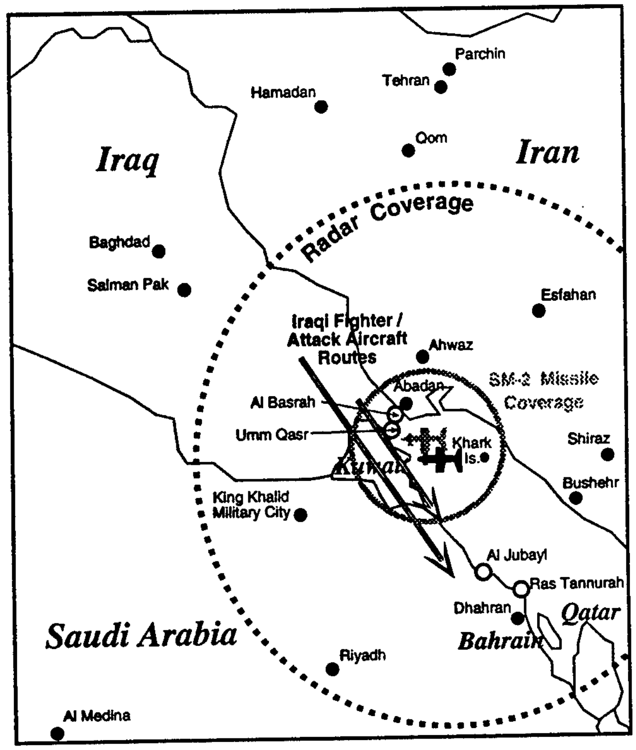
A notional 800 ton gross take-off-weight (GTW) wingship was used for all combat missions, with only slight changes in configuration. A payload fraction of 0.2 (160 tons) was used for this wingship, and a fuel fraction of 0.36 (288 tons). The range for this WIG design has been estimated to be 2900 nms (5370 km), with a speed of 330 knots (611 kms/hour). The WIG was configured with a VLS containing 48 missile cells capable of handling any of the types of missiles required for the simulated combat missions (in some cases, multiple missiles can be loaded into a single cell). For two of the missions (NTACMs and SLCMs) the missile load was somewhat less than the theoretical capacity of the VLS due to WIG weight constraints. The heavy lift WIG was assumed to be a 3,000 GTW design with a payload fraction of 0.2 (600 tons), and at fuel fraction of 0.41 (1,230 tons). The range of this craft is estimated to be 4600 nautical miles, with a speed of 320 knots.

2. Air Defense Application

The air defense mission was performed in the northern Persian Gulf where it was feasible to intercept both Fulcrums and the Fitters en route to their targets from air bases in central Iraq (see ***Figure 6***). The missile load for the air defense WIG was 48 standard missile-2 block IV (SM-2 IV). Targeting information was provided by a second WIG equipped with a three dimensional, phased array (Aegis-type) radar (although relay of AWACS information to the air defense WIG was also considered). The missile load proved sufficient to keep an air defense WIG on station for approximately four hours during the high-intensity Day 1 conditions of this threat scenario. The WIG then returned to Ad Daman for resupply (3-1/2 hours to reload missiles plus approximately 1/2 hour transit time to and from station). Subsequent to Day 1, resupply of the air defense WIG was discontinued.

3. NTACM Application

Two wingships were employed in the NTACMs role, each equipped with 32 NTACMs (one per cell) as their primary missile, and 32 advanced medium-range air-to-air missiles (AMRAAMs); (configured for vertical launch, four per cell) for their secondary air defense mission (see ***Figure 7***). Both NTACMs wingships performed two interdiction missions against threat ground units early on Day 1. One WIG was assigned a primary mission of destroying the threat FARP. This WIG also had a secondary mission to attack SCUD launchers as real-time targeting information became available The other WIG was dedicated against maneuver units. Subsequent sorties of both WIGS (after resupply) targeted threat maneuver units. The WIGs moved to approximately 50 kms off-shore for these missions, changing locations rapidly in between launches. NTACM Block I submunition warheads were used against the FARP and the SCUD launchers, while NTACM Block II was used against maneuver targets.



OBJECTIVES

To assess the advantages of deploying high speed, sea-based air defenses in coastal areas to acquire/destroy aircraft at distances far removed from friendly ports/ troop positions.

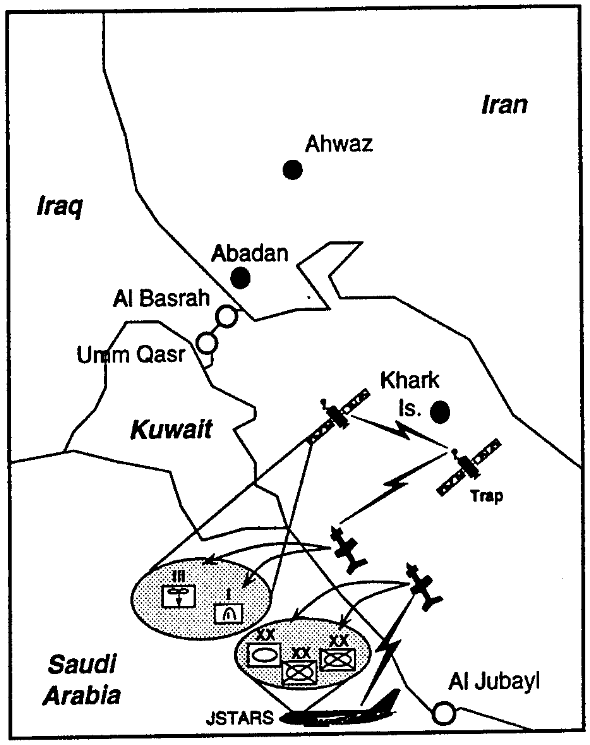
CONCEPT OF OPERATIONS

- Air Defense Missile Wingship and Air Defense Radar Wingship deploy along over-water flight paths used by Iraqi fighter and attack aircraft
- Radar Wingship acquires ingressing hostile aircraft and directs Missile Wingship to destroy targets

SYSTEM CHARACTERISTICS

- Air Defense Missile Wingship
  - 48 missile launch cells loaded with 48 SM-2 Blk IVA missiles (range: 167 km)
- Air Defense Radar Wingship
  - 3-dimensional, phased array (Aegis/GBR-type) radar (acquisition range: 500 km)
  - 8 missile launch cells loaded with 32 AMRAAM for self defense

Figure 6. Air Defense Mission Summary.



OBJECTIVES

To assess the advantages of deploying high speed, sea-based tactical fire support missile systems against massed armored formations, critical mobile targets, and forward aerial refueling points (FARPs).

CONCEPT OF OPERATIONS

- NTACMs Missile Wingships deploy to conduct interdiction of massed armored formations, Scud missile launchers, and FARPs
- Targeting data passed from JSTARs, WIG-launched UAV and/or tactical intelligence sources

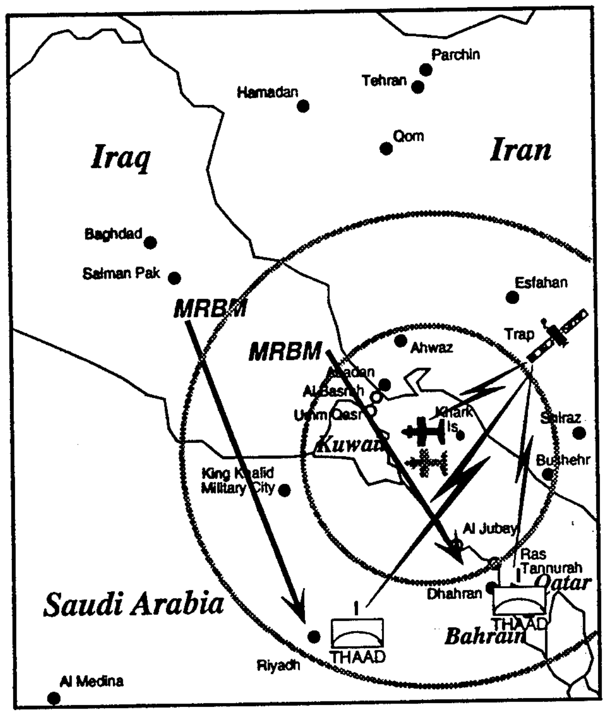
SYSTEM CHARACTERISTICS

- NTACMS Missile Wingship
  - 32 missile launch cells loaded with 32 NTACMS Block I and Block II missiles (range: 160 km)
  - 8 missile launch cells loaded with 32 AMRAAM for self defense

Figure 7. NTACMS Mission Summary.

4. TMD Application

The WIG equipped to perform TMD missions operated in tandem with the forward-based radar WIG, much like the air defense variant (see ***Figure 8***). The TMD WIG was equipped with 40 SM-2/low exoatmospheric projectile (LEAP) missiles (one per cell), and 32 AMRAAMs (four per cell) for a secondary self-defense/air defense mission. The radar platform WIG passed acquisition targeting data to both the LEAP WIG and to ground-based THAAD launchers around Riyadh and Dhahran.



OBJECTIVES

To assess the advantages of forward deployment of theater missile defense assets using a high speed, sea-based acquisition, tracking and launch platform to counter SSM launches.

CONCEPT OF OPERATIONS

- **Deployment to the far northern region of the Persian Gulf to counter SSM threat posed by Iraqi SCUD/ MRBMs.**
- **WIG will acquire/destroy airborne SSMs.**
- **Acquisition and tracking data on unengaged missiles will be passed back to ground-based TMD.**

SYSTEM CHARACTERISTICS

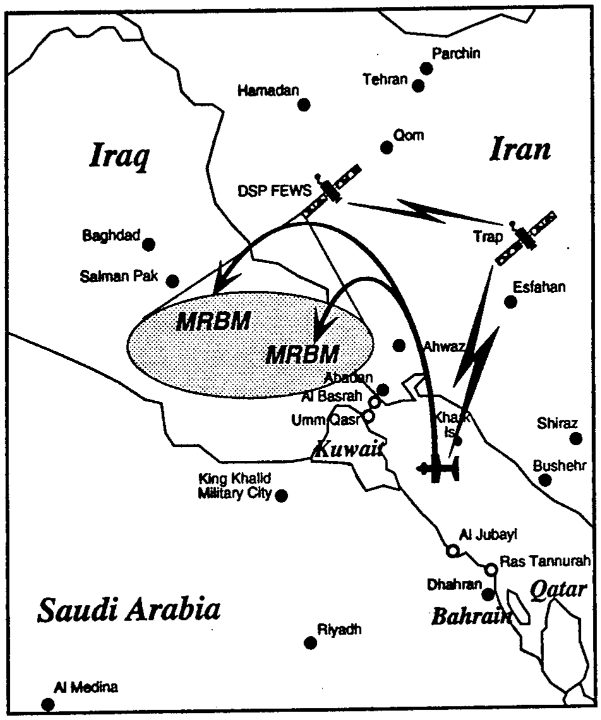
TMD Wingship:
- **40 missile launch cells loaded with 40 SM-2 / LEAP (range 167 km)**
- **8 missile launch cells loaded with 32 AMRAAM for self-defense**

Figure 8. TMD Mission.

The TMD WIG was deployed to the northern Persian Gulf, with its primary mission to intercept launches of the medium-range ballistic missiles (MRBMs) from Central Iraq. Both the TMD and radar WIGs remained on station throughout the three days of conflict.

5. SLCM Application

The SLCM WIG carried a load of 32 Tomahawk land attack missiles (TLAMs), one per cell for its primary mission, and 32 AMRAAMs for self protection (see ***Figure 9***). It was deployed to the northern Persian Gulf to react on short warning to detections of launch preparation activities at MRBM sites.



OBJECTIVES

To assess potential advantages gained by using WIGs to launch sea-based cruise missiles.

CONCEPT OF OPERATIONS

- **Deploy WIG to northern Persian Gulf.**
- **Download satellite data on MRBM roll-out/set-up and launch cruise missile strikes.**
- **Launch Tomahawks against air defense, C3 and other fixed, hardened targets in Baghdad, Baghdad environs, and throughout south/central Iraq.**

SYSTEM CHARACTERISTICS

Cruise Missile Wingship:

- **32 missile launch cells loaded with 32 Tomahawk Land-Attack Missiles (TLAM)**
- **8 missile launch cells loaded with 32 AMRAAM for self-defense**

Figure 9. Sea-Launched Cruise Missile Mission Summary

The cruise missile technology employed for this mission presupposed future development of capabilities to rapidly reprogram the missile just prior to launch, and/or update missile target data in-flight. A northern Gulf deployment was essential to this mission in order to minimize fly-out time to the target. The modeled MRBM preparation time was approximately 30-45 minutes. The cruise missile fly-out time to targets in southern Iraq would preclude launch from platforms in the southern Gulf given this short targeting window. Only one wingship was employed in this mission.

6. Lift Application

The lift scenarios introduced 3,000 ton GTW WIGs as force generation assets capable of augmenting the base case U.S. early entry force package. Of the three lift variants considered (corps, ACR and small unit), the corps was ruled out because initial analysis indicated the number of WIGs required would be prohibitive. Additionally, time required for assembly of units in CONUS and debarkation to wartime positions in Saudi Arabia would probably exceed the scenario timelines. Examining the other two lift packages, it was decided to start analysis with the tailored, small units designed to fill gaps identified in U.S. combat capabilities in the base case. This analysis indicated requirements to enhance U.S. capabilities in three critical areas: air defense, missile defense, and long-range interdiction of maneuver forces. The small unit force package, therefore, included 8 Patriot launchers, 9 THAAD launchers, 18 MLRS launchers, 24 Marine LAVs specially configured for air defense (25mm guns and Pedestal Mounted Stingers), and all associated munitions reloads, logistics and other support assets. The results of this lift scenario were sufficiently interesting that additional effort was devoted to analysis, while modeling of the ACR was deferred.

E. COMPARISON OF BASE CASE AND WIG EXCURSION RESULTS

This section contains results summaries of the base case scenario and WIG simulation excursions. The first part of the section focuses on a comparison of the base case and combat WIG campaigns, highlighting the collective impact of the WIGs on combat outcomes. Following this scenario overview are brief discussions and statistical summaries of the individual WIG missions. Finally, the two lift excursions are described and compared with the previous cases.

1. Summary of Base Case and Combat WIG Simulations

The threat concept of operations (CONOPS) involved a combined arms corps moving south along two axes to overrun U.S. units and to occupy the staging areas of Al Jubayl and Dhahran. These ground forces were supported by air and missile strikes designed to destroy or disrupt U.S. long-range interdiction capabilities. Threat air and missile attacks therefore focused on U.S. fixed-wing and helicopter bases, and on the nine XVIII Airborne corps MLRS launchers.

The U.S. base case CONOPS centered on exploiting its range and precision targeting advantages to interdict enemy advances and allow time for introducing reinforcements. Initial targeting priorities included suppression of enemy air defenses (SEAD; especially SA-10 radars and launchers) using carrier aviation armed with HARM Block IV. In the first four to twelve hours of the scenario, U.S. targeting was then scheduled to switch to interdict threat maneuver forces. Initial fixed-wing air strikes were to be supplemented by helicopter and MLRS/ATACMS attacks as threat units moved into range.

The maps on the following pages depict relative U.S. and threat unit positions and status at various stages of the base case and combat WIG campaigns. ***Figure 10*** shows each sides' status sixteen hours after the lead threat elements began to advance at midnight (followed by the main body of ground forces

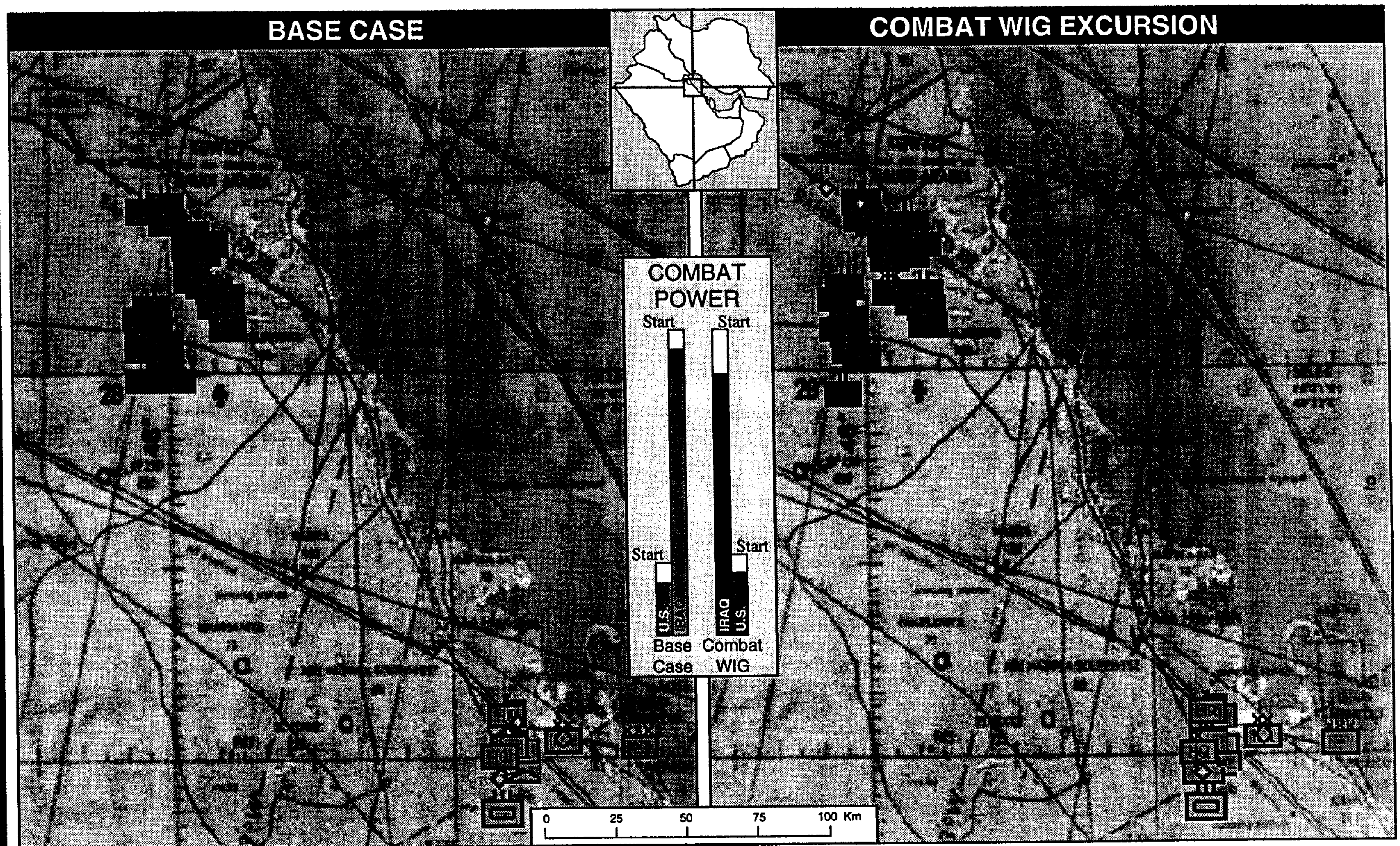


Figure 10. Comparative Combat Results Summary: Day 1, 1600.

beginning at 0400). U.S. unit positions are also shown at the southern part of the map (note: 82d Airborne Battalion positions are indicated by headquarters units to the north and west of U.S. positions, the MEB is in a reserve position in the south).

Each sides losses are depicted in two ways. Units that have suffered concentrated losses sufficient to render them combat ineffective are shown as small diamonds. The level of attrition necessary to cause a loss of unit integrity varies depending primarily on unit type, size and operation, as well as casualty rate (a unit can sustain greater losses without becoming ineffective if the losses occur over a longer time period). Other unit losses (insufficient to cause "unit death") cannot be distinguished from the symbols on the maps, but the combat power bars provide an approximation of each sides' relative strength. These bars were derived by a METRIC post-processing routine that tabulates each sides' starting and current equipment, applies a weighted score to each system, and then displays a cumulative "snapshot" of each sides' combat potential (these post-processed scores are derived from U.S. Army and OSD qualitative measures of effectiveness and are not used in METRIC combat calculations).

According to ***Figure 10***, therefore, the U.S. has lost three units (two are colocated) by Day 1, 1600, in the base case (two MLRS batteries, and an artillery battalion). The third MLRS battery has also been reduced to one effective launcher at this point, meaning that eight of the nine original MLRS have been eliminated. U.S. long-range firepower has thus been drastically reduced. In total, the U.S. has lost 37 percent of its theoretical combat power (or 63 percent remaining) by this point in the scenario.

On the threat side, the U.S. SEAD campaign has been marginally effective, with several SAM radars and launchers destroyed. However, only one of the three high priority SA-10 units has been reduced in capability. This is in part due to U.S. data latency and unit misidentification, but is more a result of the MiG-29s performing combat air patrol (CAP) over threat forces. While U.S. air superiority aircraft are able to defeat opposing aircraft on a one-to-one basis, carrier-launched strike aviation are still deterred in some cases from reaching their primary targets. A combination of U.S. aircraft non-availability and continued strong threat air defenses has limited the effectiveness of U.S. interdiction attacks, initiated in the two hours preceding the map depiction. Threat strength is thus at 92 percent of the starting total.

In the combat WIG excursion on Day 1, 1600, the relative positions are improved for the U.S. The air defense, and to a lesser degree TMD, WIGs have helped both U.S. defensive and offensive capabilities. Defensively, higher threat aircraft losses have reduced the number of successful attacks on U.S. ground forces. Offensively, the degraded enemy CAP has relieved some of the pressure on U.S. air forces and allowed more successful strikes—particularly of the critical SEAD missions. As a result, the U.S. has doubled the number of effective kills of threat air defense units (from five in the base case to ten) by destroying missile radars. The Flaplid radar site in one SA-10 battery has been destroyed (although the other two SA-10 units were still missed) and two other air defense units were entirely destroyed. The reduced air defense environment has allowed more successful air interdiction of threat maneuver units, and these attacks have been augmented by the first attacks from each of the NTACMs WIGs.

The greater success of the U.S. air defense campaign has also helped preserve more of its ground forces, including all three MLRS units (although reduced to one effective launcher each). U.S. combat power has thus been attrited but not as significantly as in the base case. Threat losses have doubled over the base case. Relative standings have the U.S. at 73 percent of starting effectiveness versus 85 percent for the threat force.

Figure 11 shows relative unit positions and conditions on the second day of the engagement. In the base case, the U.S. interdiction has been generally unsuccessful and the threat ground forces have advanced

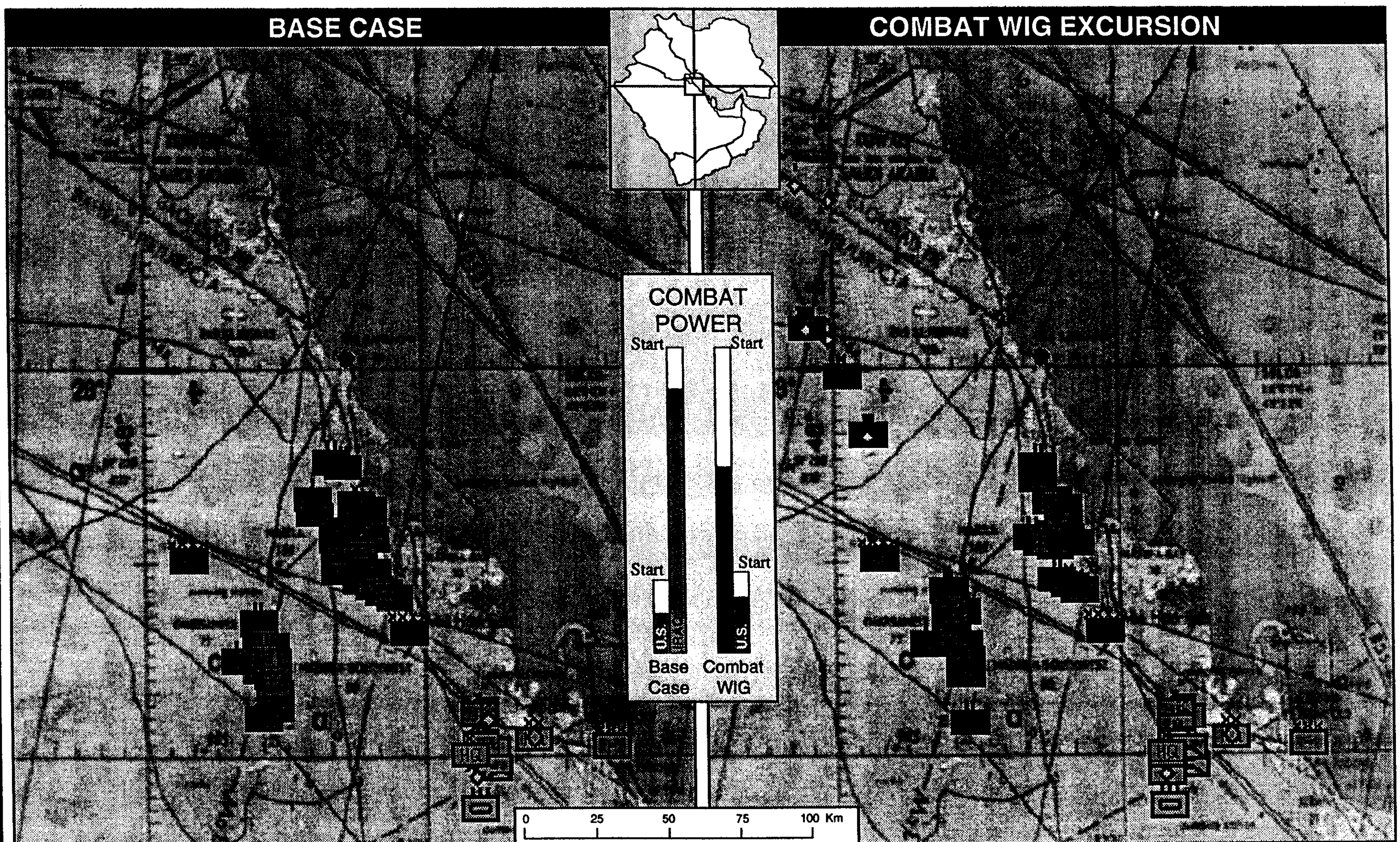


Figure 11. Comparative Combat Results Summary: Day 2, 1600.

in good order along both axes. Both sides have continued to exchange air attacks, but not at the high tempo of the first day. As a result, no additional units have been lost by either side. Equipment losses from the air and missile attacks have continued, however, with the U.S. reduced to 47 percent effectiveness and the threat to 85 percent.

The ***Figure 11*** maps and bars show a much more significant threat attrition in the combat WIG excursion. The most apparent change is along the inland advance axis where units have been strung out over 200 kilometers due to a combination of attrition, suppression, and loss of higher-level command and control. Less obvious at this level of resolution, the main bodies of troops in both axes have also been disrupted and lost inter-unit cohesion at regimental, brigade, and division levels. Most of the OPFOR maneuver units and many support elements have suffered some attrition and four brigades are less than 50 percent combat effective. The greater success of U.S. interdiction can be attributed mostly to the two NTACMs WIGs, operating off-shore contiguous to the area of OPFOR movement. However, the increased survivability of U.S. ground and air forces due to the air defense WIG interdiction of threat aircraft also contributes significantly to preserving U.S. long-range interdiction capabilities. At this point, most losses on the U.S. side have been sustained by the northern 82nd Airborne element and the Marine reserve. Overall, the U.S. forces are at 66 percent strength while the threat has been reduced to 59 percent.

Figure 12 shows relative unit positions at a higher map resolution on the morning of the third day of combat. In both the base case and excursion, artillery and direct fire contact has been initiated in the north. In the base case, the threat has overrun the U.S. forward positions, although sustaining heavy losses in the process. Lead elements of two tank brigades have bypassed remaining U.S. forward positions and are advancing on the rear area (including the helicopter base and XVIII Airborne Corps headquarters). Of the defending U.S. forces, only the western 82nd elements are still viable, with little artillery or air support. The Marine reserve, which moved north to defend against the first threat attacks, has also been overrun. Meanwhile, the flanking threat force is in good order and has taken relatively light losses due to the concentration of U.S. fire to the north. Total U.S. strength is down to 34 percent, while the threat is at 72 percent, concentrated mostly in the flanking force.

The combat WIG excursion follows a similar sequence of events, although in this case the threat force has been delayed by the U.S. attacks and has only just began its northern assault. Although badly attrited, the U.S. MEB has moved to a blocking position in the north, while the second battalion of the 82nd Airborne is holding its defensive position in the west. The threat has been reduced to 41 percent effectiveness versus 47 percent for the U.S., but it still has a greater than 3:1 direct firepower advantage. Without additional air and artillery support the U.S. forces are still in a precarious position.

Figure 13 shows unit positions near the end of the engagement. In the base case, U.S. ground force resistance has effectively stopped and several threat units have bypassed to the south and east of the U.S. positions. The situation is much the same in the combat WIG excursion, despite the greater success of earlier U.S. attacks. Even in the excursion, the preponderance of threat ground forces negates the offensive and defensive advantages gained from the WIGs (primarily the NTACMs and air defense variants), and U.S. positions are overwhelmed. Although the U.S. holds out longer in the excursion, the introduction of limited numbers of combat WIGs was insufficient to stop the threat advance. Numerous threat units were destroyed, but the remaining forces (38 percent of original combat power versus 71 percent in the base case) are still sufficient to overpower the lightly armed U.S. forces. U.S. strength is 39 percent in the combat WIG excursion versus 30 percent in the base case at the time of the figure.

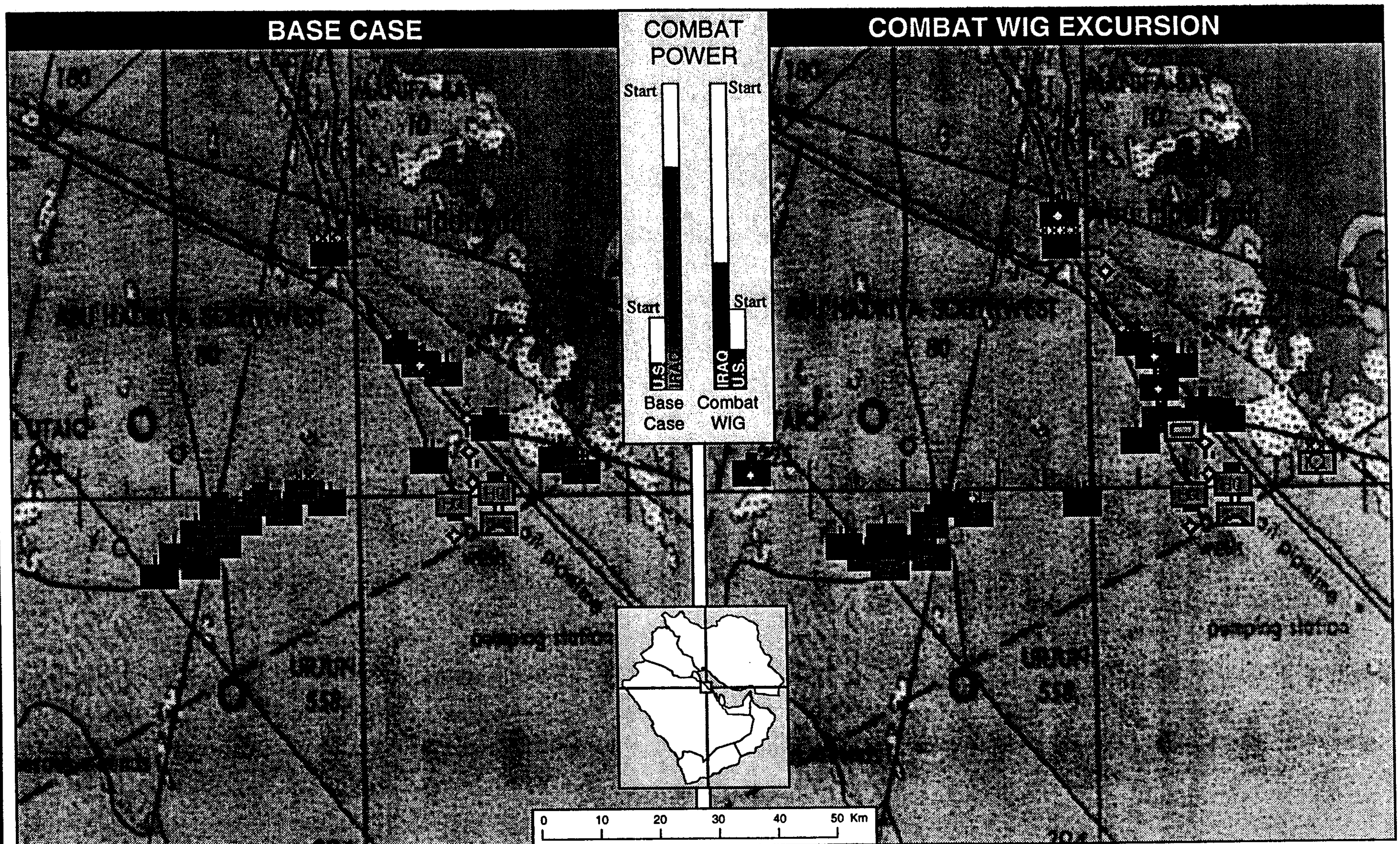


Figure 12. Comparative Combat Results Summary: Day 3, 0600.

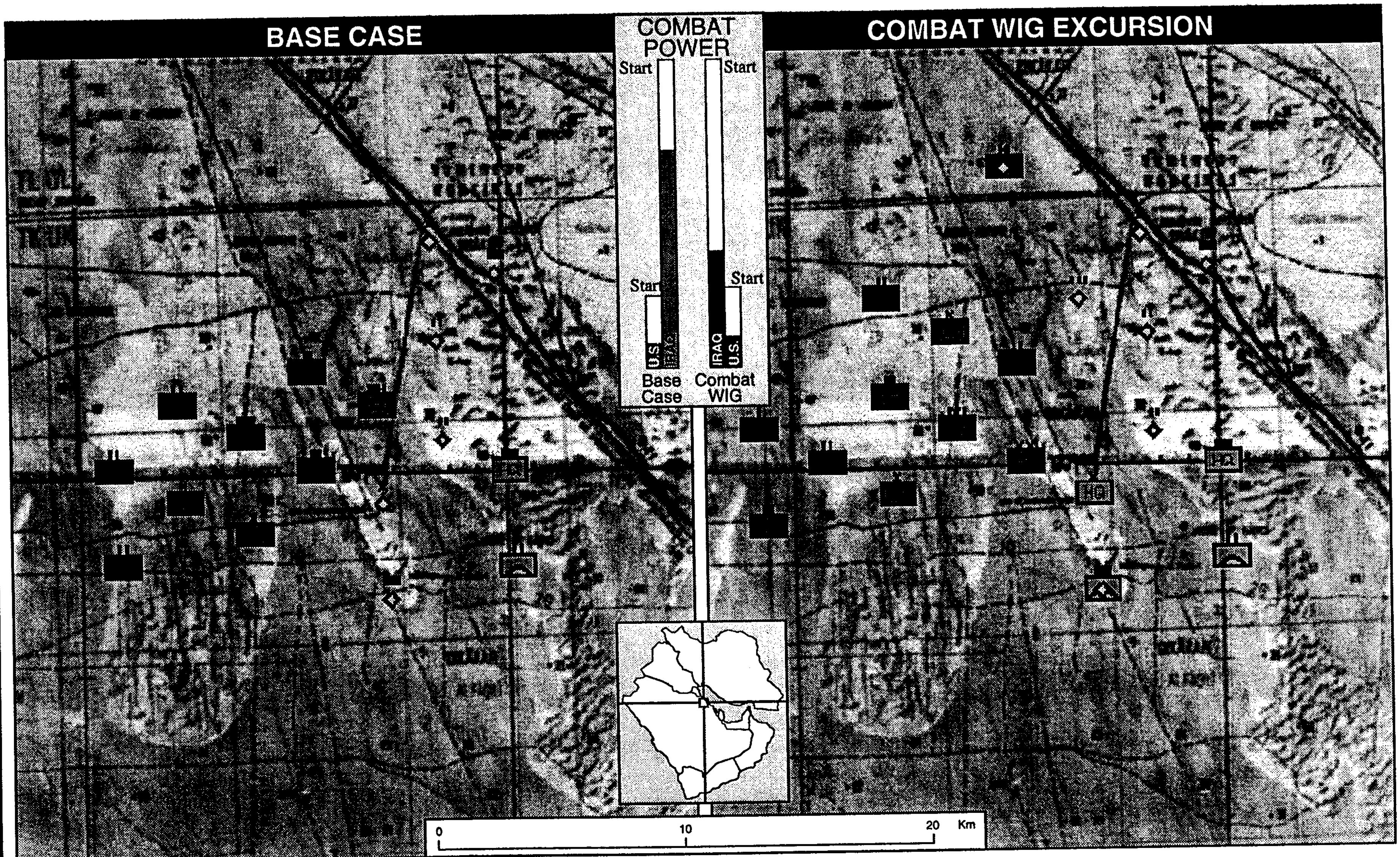


Figure 13. Comparative Combat Results Summary: Day 3, 1400.

The overall campaign impact of the WIG combat missions is depicted in ***Figure 14*** As the chart shows, threat losses more than double in the WIG excursion. Despite these losses, however, the threat force retains an overwhelming force advantage as direct fire exchanges commenced on Day 3. This advantage was achieved by threat abilities to neutralize key U.S. assets (primarily MLRS and aircraft) early in each scenario. Consequently, it appears that a potential key to increasing U.S. survivability, and consequently lethality, is to augment the U.S. ground force ability to defeat enemy air attacks. Detailed analysis of base case and excursion results supported development of the lift excursion (described in paragraph 6), in which relatively small numbers of highly lethal advanced systems were added to the U.S. ground forces. Statistics associated with specific combat WIG missions are included in the paragraphs below.

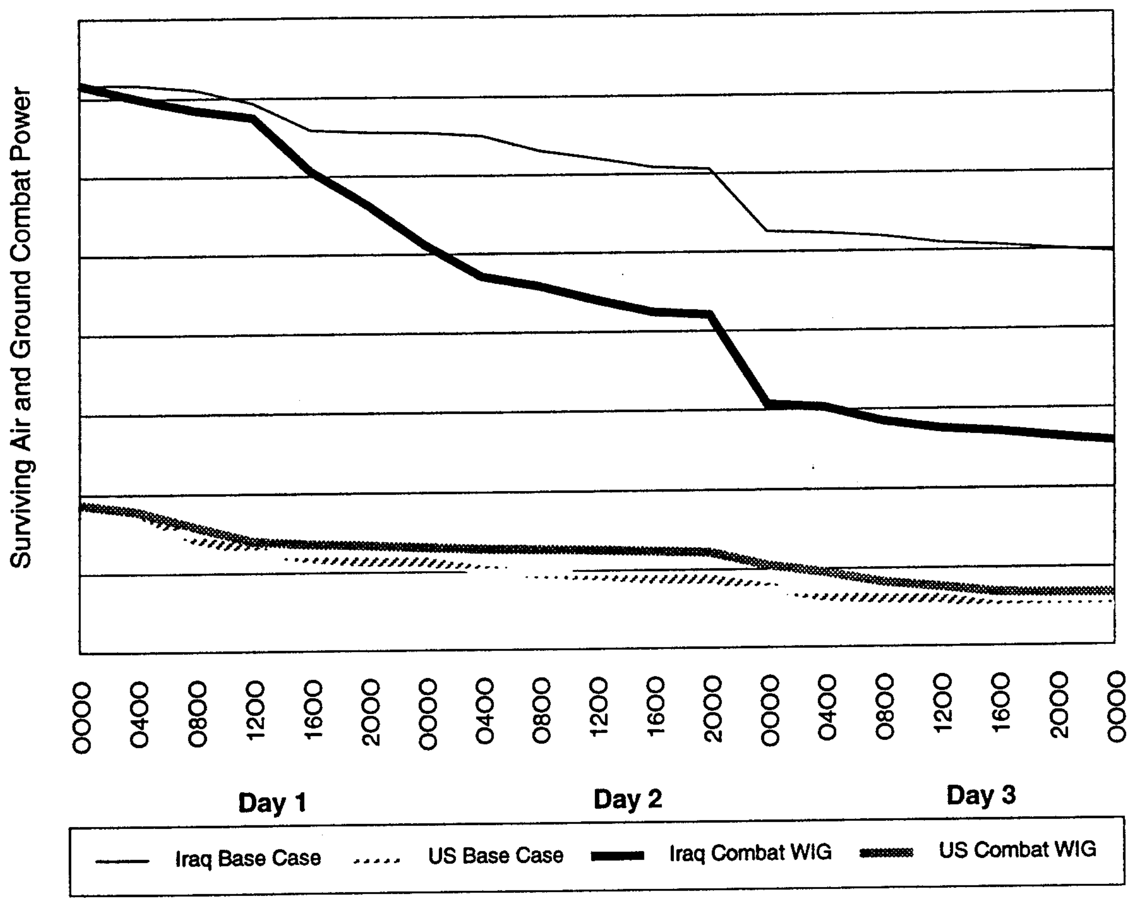


Figure 14. Combat WIG Campaign Impact.

2. Air Defense Mission Results

The air defense WIG deployed to the northern Persian Gulf early on Day 1. In the high-intensity early hours of the conflict, this WIG craft was successful in engaging a large number of Fulcrums attempting to push the threat air defense zone out into the Gulf against U.S. ground attack sorties. As shown in ***Figure 15,*** the air defense WIG was the largest contributor to Blue air defense during the early stages of the battle. By the end of Day 1, this combat WIG killed 32 Fulcrums, and damaged several other aircraft. After Day 1, the air defense WIG was not further resupplied.

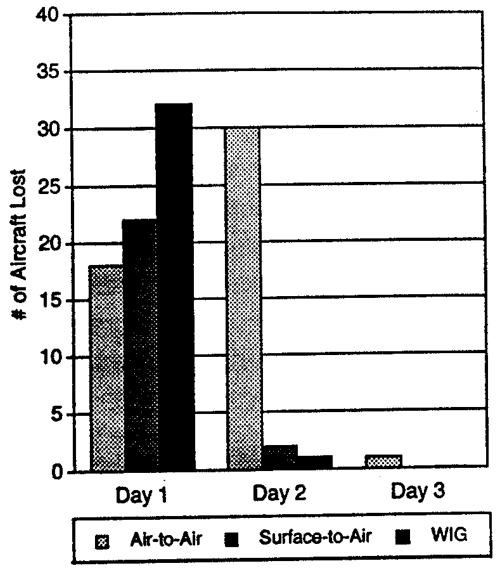


Figure 15. Iraqi Aircraft Losses in Combat WIG Excursion.

Figure 16 shows relative U.S. and Iraqi aircraft losses over time in the base case and combat WIG excursion scenarios. The impact of the WIGs can be seen in the numbers of aircraft losses sustained by both sides through 1600 Day 1. Threat losses are almost double in the combat WIG excursion over the base case (108 versus 58). About 60 percent of these losses are directly attributable to the air defense WIG, while the rest are a combination of improved U.S. aircraft effectiveness (due to the reduced air threat) and NTACMs strikes against the enemy FARP. While the total number of threat aircraft losses was virtually identical by the conclusion of the base case and combat WIG scenarios, those losses thus occurred much earlier in the excursion. As a result, U.S. air and ground forces survived longer—particularly strike aviation and MLRS—enabling them to inflict more attrition on threat maneuver forces (see ***Figure 17***).

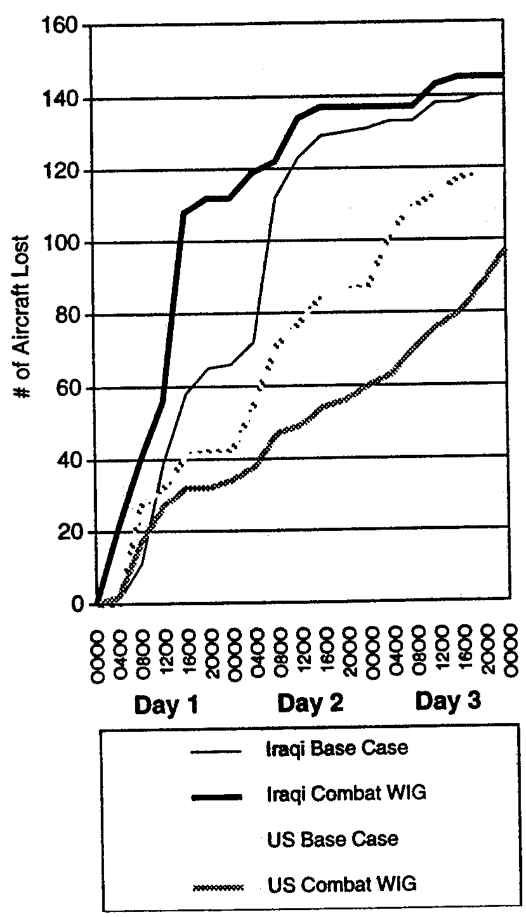


Figure 16. U.S. and Iraqi Aircraft Losses

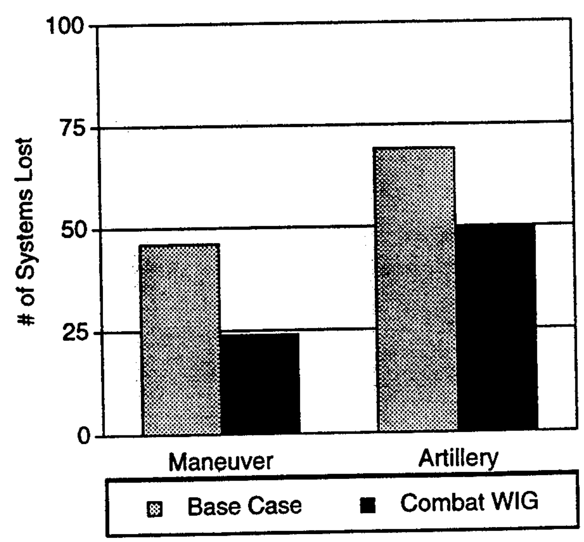


Figure 17. Representative U.S. Air-to-Ground Losses.

3. NTACM Mission Results

The two WIGs fitted out with NTACMs each performed two sorties, with standard loads of 32 missiles. Three of these sorties targeted threat maneuver units, primarily armor, with NTACMs Block II; the other sortie targeted the Iraqi FARP and a SCUD battery with NTACMs Block I submunition warheads. All four sorties were completed between mid-morning and mid-afternoon on Day 1.

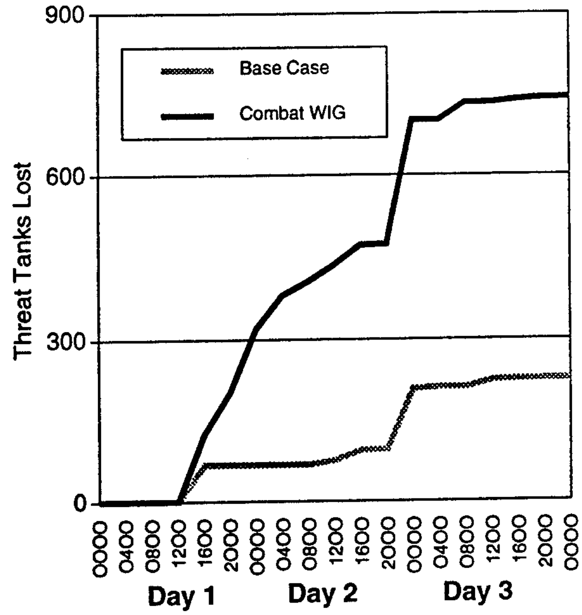


Figure 18. NTACMS Impact on Threat Tank Losses

As shown in ***Figure 18,*** Iraqi tank losses increased more than three-fold in the combat WIG excursion as compared with the base case (from 227 to 743). Only 185 of the additional threat tank losses were directly from NTACMs fires. The higher U.S. lethality with the combat WIGs, however, acted as a force multiplier for other systems. The NTACMs mission against the threat FARP, for instance, significantly improved U.S. abilities to interdict threat armor throughout Day 2 and Day 3 because it preempted a second wave of Hind ground attack sorties against U.S. MLRS and artillery that occurred in the base case. The NTACMs strike against the FARP and SCUD battery also enhanced the survivability of U.S. helicopters and freed them up to attack other targets (in the base case, the FARP was interdicted by Apaches during the night of Day 1/Day 2).

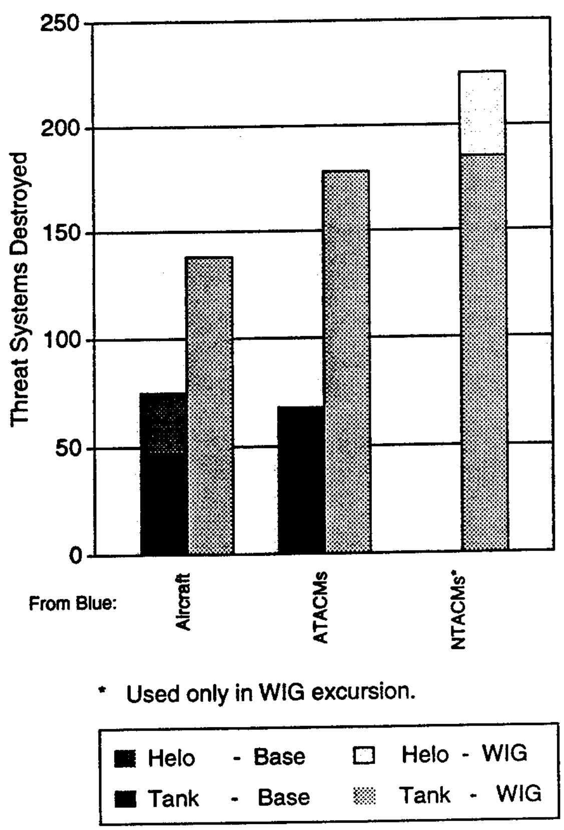


Figure 19. Threat Tank and Helo Losses.

Figure 19 shows how the NTACMs missions were indirectly responsible for increased tank kills by AH-64s, ATACMs and artillery/direct fire by limiting the damage caused by threat ground and air systems early in the combat WIG scenario. By the end of Day 3, however, the overall survival of U.S. forces remained very similar to the base case. As discussed earlier, at the time the forces approach direct contact late on Day 2, the excursion case threat force still retains an overwhelming advantage in combat power even though it is substantially weakened in comparison with the base case. For instance, the threat still retains 324 tanks in the end of the combat WIG excursion (roughly equal to the number of tanks in a U.S. armored division). This force, including other unit equipment, was still far too strong for the lightly armed U.S. units to stand against in a direct fire engagement. ***Figure 20*** shows how total U.S. losses were virtually identical by the end of each scenario.

4. TMD Mission Results

The WIG TMD mission involved one WIG armed with 40 SM-2/LEAP missiles on station to intercept MRBMs throughout the engagement. As *Figure 21* illustrates, threat MRBMs and SCUDs were able to saturate the 2 THAAD launchers comprising U.S. base case TMD, with 26 threat SSMs penetrating missile defenses. In the WIG excursion, the total number of successful threat missile strikes decreased to 8.

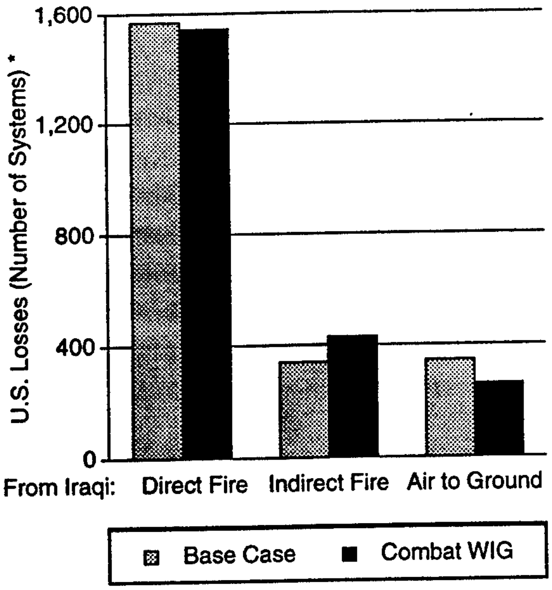


Figure 20. NTACMS Impact on Final U.S. Losses.

The LEAP WIG succeeded in destroying three MRBMs during their ascent phase, and the radar WIG provided tracking data beyond the range of the THAAD radars. Despite the improved acquisition and tracking data provided to the terminal defenses, no improvement in MRBM intercepts was seen. In both the base and excursion cases, seven MRBMs were intercepted over Riyadh and Dhahran, requiring a total of fourteen THAAD missiles. In the excursion, only one MRBM struck a target—versus five base case MRBM strikes—because of the successful intercept of three missiles by the TMD WIG, and interdiction of a fourth on the ground by the SLCM WIG (see *Figure 22*). The lack of improved terminal intercepts was probably a function of how the hand-off of forward radar data was handled in the model; although saturation of the single THAAD launchers at Riyadh and Dhahran may have also affected the outcome. Additional analysis may be appropriate to investigate both

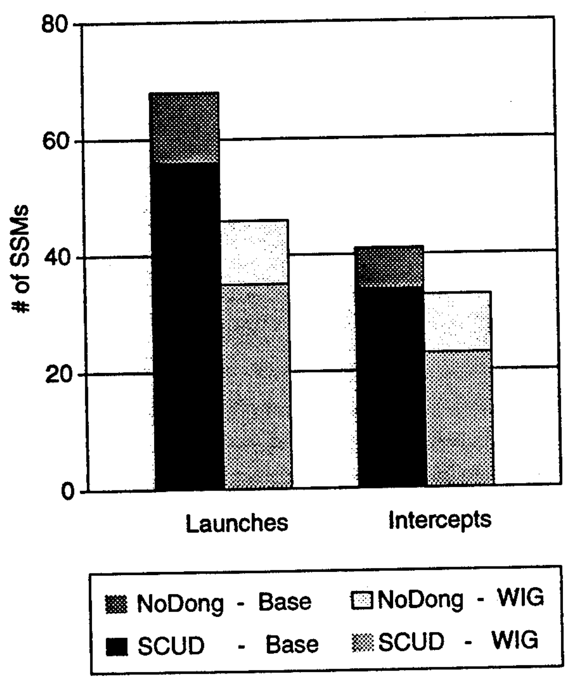
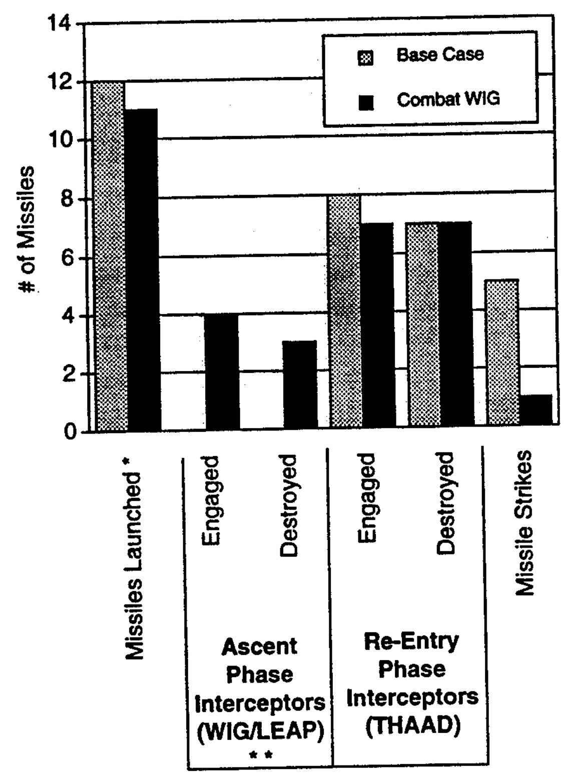


Figure 21. Summary of Threat SSMs



* One MRBM destroyed on pad by cruise missile in combat WIG excursion
** Not used in Base Case

Figure 22. TMD Results Against MRBMs.

these possibilities. Some saturation problems persisted in the excursion case, indicating a need for increased numbers of TMD launchers.

5. SLCM Mission Results

One combat WIG was deployed to the northern Persian Gulf late on Day 2 to attempt preemptive strikes against MRBM launch areas in southern Iraq. This WIG was equipped with Tomahawk cruise missiles. Once on station, the SLCM WIG waited for detections of launch preparation from overhead sensors watching the target area. The WIG's northern deployment was intended to shorten missile fly-out time to target because the anticipated reaction window, from detection to MRBM launch, was approximately 30–45 minutes.

Preparation activities at the MRBM site were detected at midnight on Day 2, and the SLCM launch occurred 25 minutes into Day 3. This rapid launch sequence on the WIG would require an ability to quickly reprogram the Tomahawk just prior to launch or in flight. Fly-out time to the target was 17 minutes and one launcher was destroyed several minutes before a MRBM would have been fired. The effect of this mission was to reduce the total MRBM firings by just one, but the mission did demonstrate the potential value of a shortened fly-out time that can result from the ability to rapidly move a SLCM platform into an extreme forward deployment.

6. Lift WIG Excursions

The purpose of the lift WIG excursions was to test the impact of introducing additional U.S. force increments into the base case scenario (i.e., without the combat WIGs). It was assumed for this initial analysis that large WIGs (3,000 ton GTW) would serve as the lift platforms. Analysis of other potential lift platforms was not conducted (in keeping with the initial task to assess potential WIG military missions, with trade-offs analysis of competing systems to follow).

Threat objectives and CONOPS were not changed from the base case to the lift WIG excursions. The only new elements were the improved U.S. offensive and defensive capabilities represented by the additional MLRS, THAAD, and Patriot launchers, and USMC LAV-AD vehicles. The early stage of the lift WIG excursion, therefore, closely parallels the base case results. By 1600 on Day 1 (corresponding to the base case unit position and status displayed on ***Figure 10***), threat forces were reduced to 90 percent effectiveness. The slightly higher threat casualties relative to the base case scenario (2% additional losses) reflect the loss of some additional aircraft to the improved U.S. air defenses. However, the overall difference is slight because the threat forces have not yet moved within range of the U.S. MLRS/ATACMS batteries.

The impact of the additional force increment on U.S. survivability to this point is more dramatic. Although the U.S. is still taking heavy losses from threat air attacks (especially helicopters), total combat strength remains at 75 percent of the starting total, versus 63 percent in the base case (note: the additional force increment also raised the U.S. combat power calculus by about 10 percent according to the methodology used so actual U.S. strength at the time is equivalent to 83 percent of the base case starting total). Most importantly, significantly greater numbers of U.S. MLRS assets are surviving as compared with the base case. In the lift WIG excursion at the time, 21 of 27 MLRS, divided into nine batteries, are still active (although three additional MLRS are killed within two hours and well before the mass of threat ground forces moves within range). In the base case at this time, eight of nine starting MLRS had already been lost. U.S. capabilities to interdict threat ground forces are thus significantly higher than in either the base case or combat WIG excursion (no MLRS survived to fire ATACMs in the base case; two NTACMs

WIGs, each with roughly an MLRS battery of firepower, and three MLRS—totaling the equivalent of nine MLRS—were used in the combat WIG excursion).

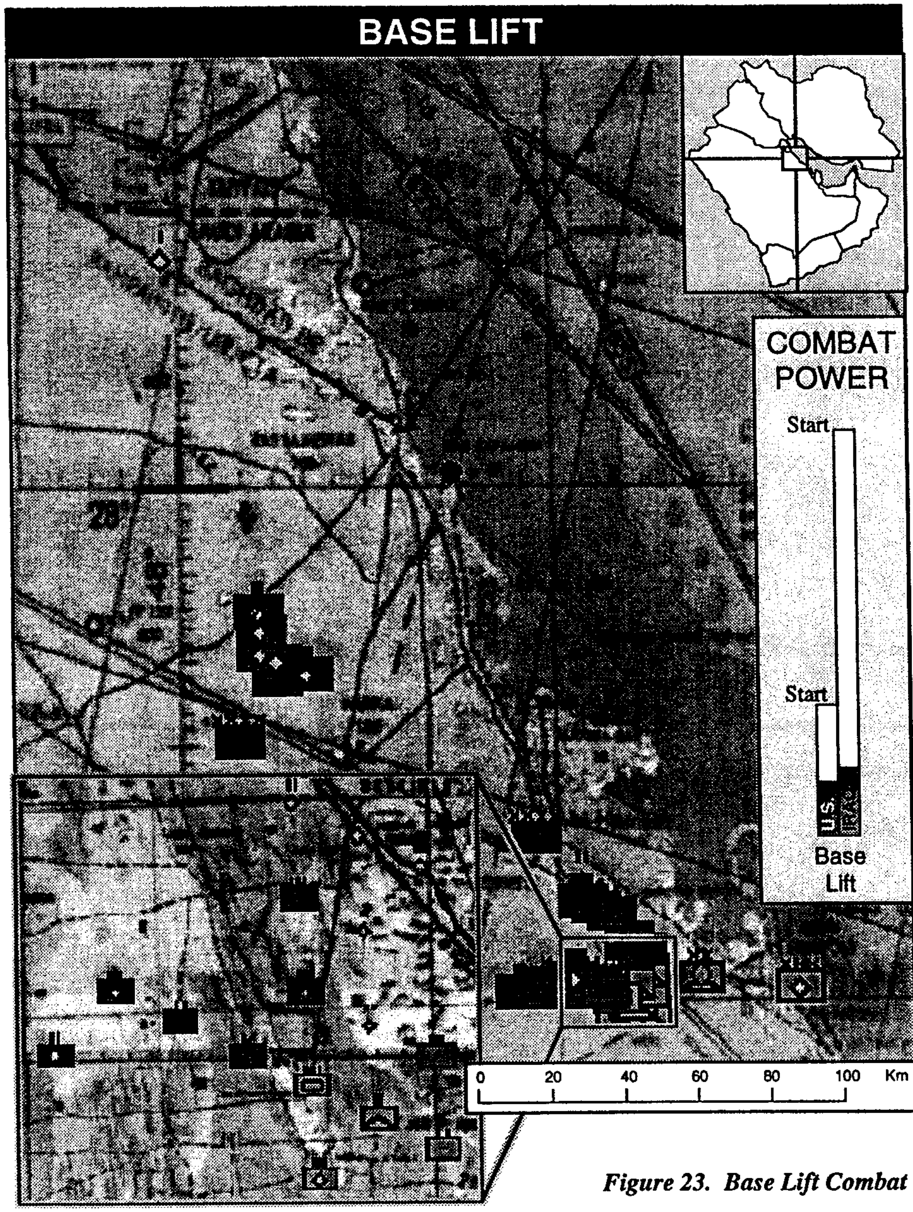
The effects of these additional U.S. interdiction resources are seen as threat losses increase substantially starting in the morning of Day 2. The biggest impact comes between midnight and 0400, when threat advances first bring them within ATACMs range. Almost 20 percent of all threat losses throughout the lift WIG excursion are sustained in this four-hour period. By 1600 on Day 2, effective threat combat power is down to 52 percent, which compares favorably with the base case at 85 percent, and the combat WIG excursion at 59 percent. U.S. survivability continues to improve relative to the base case (62 percent versus 47 percent; a 15 percent relative improvement in survivability).

As the threat forces continue their advance into Day 3, the cumulative impact of attrition becomes more apparent. In addition to the losses causing substantial reductions in unit effectiveness, significant threat forces have stalled in their advance south (see ***Figure 23***). The latter result is primarily caused by a combination of unit suppression from incoming fire, and losses of coordination with higher command and control echelons. The breakdown of C3 functions substantially undermines threat unit coordination, and in some cases, follow-on advance orders are delayed or never received. By Day 3, 0600, the remnants of the threat force reach contact with U.S. positions. By this time, the only effective threat units are elements of one armored brigade, a reconnaissance battalion, and supporting artillery and air defense. At 17 percent of starting combat strength, however, the threat force is still larger than the remaining 47 percent of U.S. forces (for instance, threat tanks number 113, as compared to 30 for the U.S.).

The map on ***Figure 23*** shows the furthest reaches of the threat advance. The map inset gives a clearer picture of the actual forces in contact as described above. Due to suppression effects, the timing of the two flanking maneuvers has been disrupted. As the map inset shows, the U.S. is able to deploy the Marine reserve in a blocking position against both attacks, rather than being overrun (as in the base case), or drawn significantly out of position (as in the combat WIG excursion). The ***Figure 23*** graph shows the difference between the relative combat strengths of both sides in the base case and lift WIG excursion. As is apparent from the chart, threat strength in the excursion is about one-fifth the base case level, while the U.S. is doing much better than in the base case. The main driver of the difference in threat combat power is represented by the steep decline in the lift WIG excursion curve on Day 2 representing the impact of the ATACMs. This sharp decline is absent in the base case due to successful threat interdiction of U.S. MLRS units. The second major decline in threat excursion strength between Days 2 and 3 is caused by the greater survivability of U.S. artillery and direct fire assets as compared with the base case.

With some of the threat combat power tied up in units farther north, and superior U.S. tactical C2, threat forces in contact actually end up facing localized inferiorities. In the hours following the ***Figure 23*** map, therefore, the U.S. is able to force the surviving threat units to retreat with substantial losses. At the end of the scenario, the last threat units to reach the U.S. positions have taken up a defensive position in favorable terrain (southwest of the inset map). At 200 miles from main supply bases and within easy reach of U.S. artillery and aircraft, however, the threat position is untenable. The scenario was therefore terminated at the end of Day 3.

Based on the success of a relatively modest introduction of force in the lift WIG excursion, the ACR scenario was temporarily suspended. Instead, additional analysis was devoted to an excursion that combined the elements of the combat and lift WIG scenarios. This scenario (henceforth referred to as the combat WIG lift excursion) added the six combat WIGs, with the same configurations and operational concepts as previously employed, to the initial lift excursion scenario. ***Figure 24*** shows the results of this final excursion.



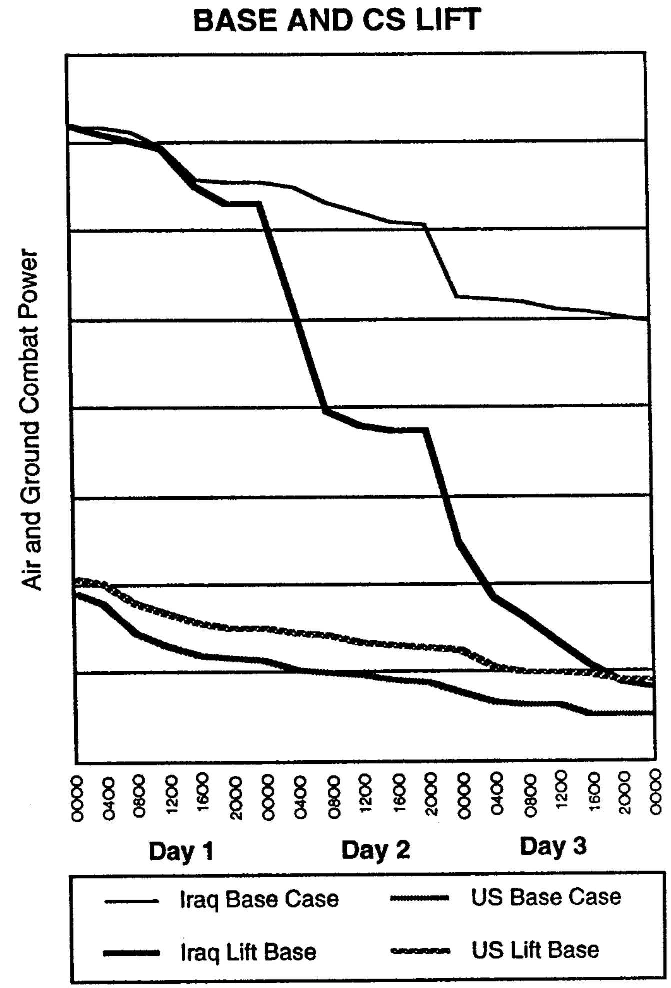
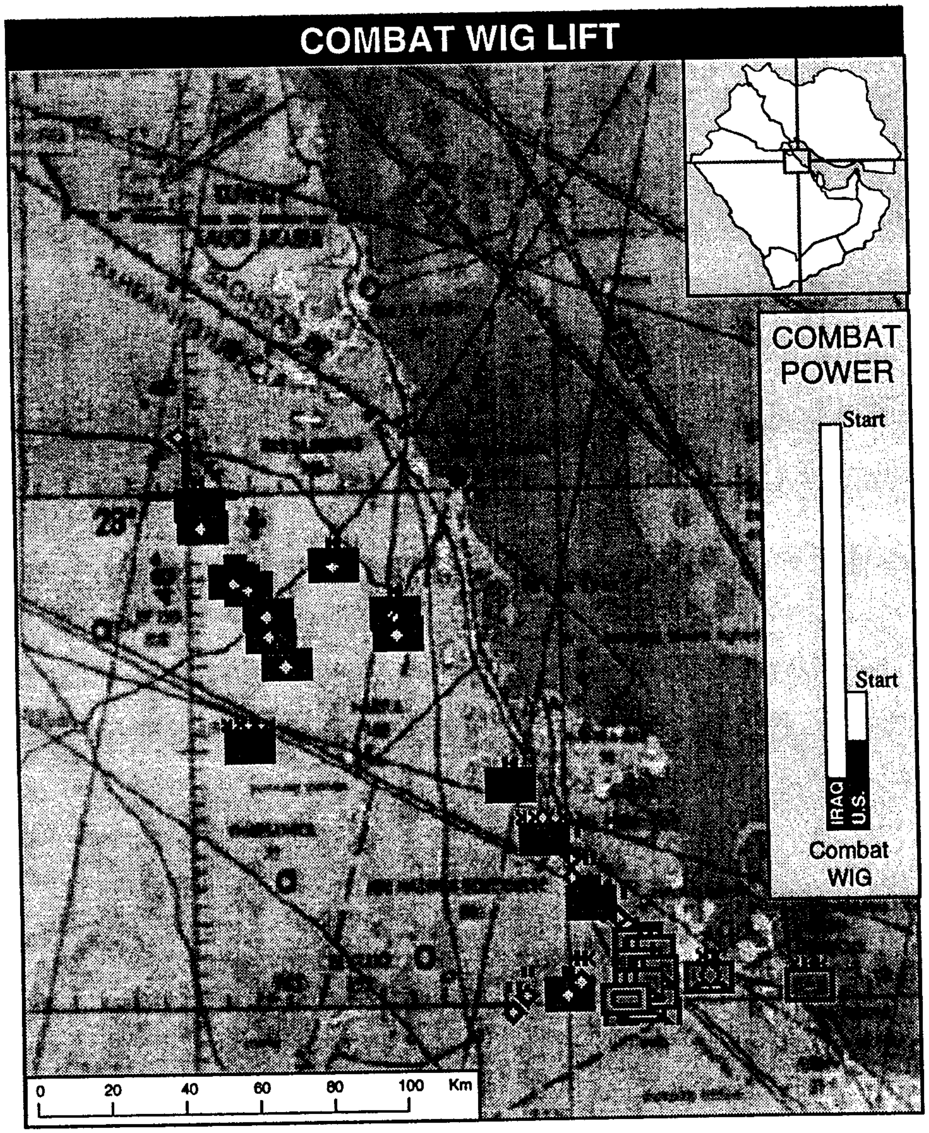


Figure 23. Base Lift Combat Results Summary: Day 3, 1400.



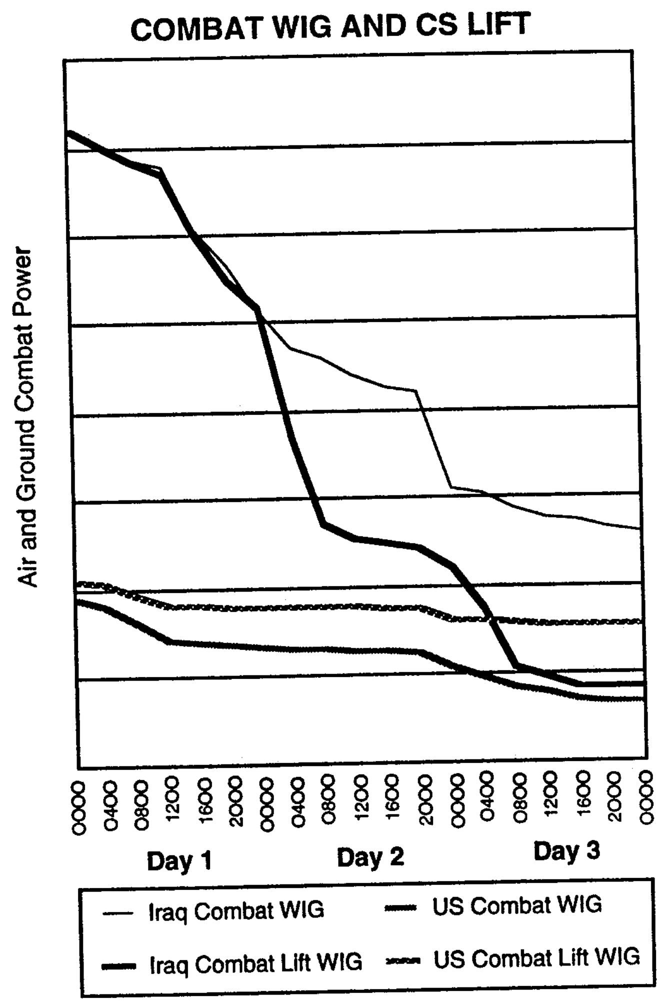


Figure 24. Combat WIG Lift Combat Results Summary: Day 3,1400.

The combination of small numbers of seaborne combat WIGs with the additional ground force increment was dramatic. In the previous model runs, the U.S. had only been able to substantially disrupt the threat advance at most once outside of the final close combat phase of the engagement (late in Day 1 with the NTACMs combat WIGs; early Day 2 with the additional lift MLRS and not at all in the base case). With the combat WIGs (especially NTACMs) and high numbers of surviving MLRS (23 in the combat lift WIG versus 18 in the lift WIG), the U.S. is able to continuously interdict the threat forces. The results of these attacks can be seen on both the map and chart on ***Figure 24***. With constant bombardment of N/ATACMs, numerous threat units are stalled or eliminated. The accompanying chart shows the steep decline in threat combat power. ***Figure 25*** shows the relative standings of both sides at the four checkpoints used earlier in this analysis.

	Starting	Day 1, 1800	Day 2, 1800	Day 3, 0600	Day 3, 1400
Base Case					
U.S.		63%	47%	34%	30%
Threat		92%	85%	72%	71%
Force Ratio (Threat: U.S.)	3.8:1	5.5:1	6.9:1	8.3:1	9.1:1
Combat WIG					
U.S.		73%	66%	47%	39%
Threat		85%	59%	41%	38%
Force Ratio (Threat: U.S.)	3.8:1	4.5:1	3.4:1	3.3:1	3.8:1
Lift WIG					
U.S.		75%	62%	49%	47%
Threat		90%	52%	24%	17%
Force Ratio (Threat: U.S.)	3.5:1	4.2:1	2.9:1	1.7:1	1.2:1
Combat Lift WIG					
U.S.		86%	84%	76%	74%
Threat		84%	34%	19%	12%
Force Ratio (Threat: U.S.)	3.5:1	3.4:1	1.4:1	0.9:1	0.6:1

Figure 25. Relative Combat Standings at Key Engagement Times

F. CONCLUSIONS

Based on the analysis conducted, WIGs appear to have a high potential to perform militarily useful missions. The addition of a relatively modest force of six combat WIGs and critical ground combat assets reversed the base case outcome in the final excursion as the Figure 25 table shows. The improvements to U.S. force lethality and survivability in the successive cases are significant and traceable to the new elements represented by the WIGs. The firepower of the NTACMs and MLRS/ ATACMs units play the most prominent roles in defeating the threat forces. The importance of the additional WIG- and ground-based air defenses in protecting the U.S. forces, however, should also be emphasized.

Having stated that a high potential for militarily useful WIG missions exists, it is important to note several caveats. Most significantly, the chosen scenario represents an almost ideal proving ground for the selected WIG applications. The presence of a heavily mechanized force, moving a long distance in open terrain adjacent to coastal areas, presents an optimal interdiction target set. This does

not mean the scenario is unrealistic for planning purposes, but the WIG roles must be evaluated against the range of potential conflict environments involving U.S. forces. Similarly, alternative operational concepts for WIG employment could significantly change their relative combat contributions.

Related to the previous caveat is the need to assess other potential WIG applications. Several possibilities such as mine warfare, special operations and amphibious assault seem appropriate to the existing scenario. Other scenarios involving different conflict environments and intensities would probably suggest additional applications for consideration. Assuming that only small numbers of WIGs would ever be available for deployment—consistent with current capital ship numbers—it will be important to demonstrate multi-mission flexibility. The viability of WIG concepts would be further enhanced if commercial or dual-use applications could be developed. The ability to operate in a wide variety of roles will therefore be key to proving WIG concept utility.

Another scenario consideration that should receive special attention is the ability of WIGs to operate in nuclear, biological and chemical (NBC) environments. Given continued proliferation trends, all major U.S. force structure planning should include the possibility of threat employment of NBC weapons. If WIGs can operate in such environments, other mitigating technical and operational factors may be offset. The speed and mobility of combat WIGs may make them more difficult targets for NBC weapons than stationed ground forces. If lift WIGs can operate at low/no infrastructure locations, U.S. power projection capabilities would also be significantly enhanced, especially if traditional air and sea ports have been shut down due to NBC use. The integration of conventional and NBC operations, therefore, appears to be an important area for future WIG assessments.

Several caveats emerging from the current analysis concern the technical viability of WIG concepts. Detailed engineering studies obviously must be conducted, although such are outside the purview of this analysis. Some basic technical factors (e.g., weight and volume limitations, fuel fractions, etc.) were considered and additional model-assisted analysis could be conducted. A principal focus for this analysis should be to conduct vulnerability assessments of WIG concepts under different operational conditions. These assessments could be done based on one-on-one or few-on-few engagements, as well as in broader scenario contexts. The results of this analysis will not provide definitive WIG vulnerabilities (impossible without tests against a real system), but will provide important benchmarks for WIG designs. If WIG designs cannot meet vulnerability/survivability criteria, then overall military utility must be questioned.

Possibly the most significant obstacle to WIG development is the projected cost of the technical solution. Cost effectiveness will be key in determining if WIGs can perform missions better than competing platforms. Detailed cost estimates should be conducted and factored into existing and future operational assessments. The operational integration is important because economic trade-offs between systems should be balanced with potential military consequences. For instance, the deterrent value of being able to deploy and loiter significant WIG combat power around the world in very short time periods should be factored into the research, development and acquisition planning process. If future WIG utility assessments indicate an opportunity for filling a crucial U.S. military requirement, then the cost of not building and deploying such a system or force, both in economic terms and in human lives, may be high if the required mission cannot be adequately fulfilled by other means. Future assessments should include emphasis on identifying such opportunities for unique WIG contributions to U.S. military capabilities.

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WINGSHIP ALTERNATIVE MISSION ANALYSIS

18 MARCH 1994

NAWCADWAR CODE 3031

NAVAL AIR WARFARE CENTER

AIRCRAFT DIVISION WARMINSTER

WARMINSTER, PA 18974-5000

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1.0 OBJECTIVE / APPROACH

The primary military use of a future large "wingship" has been identified as a transport platform which will improve U. S. airlift and sealift capabilities. An analysis of this mobility role is the main thrust of the activities of the mission analysis team assembled for the ARPA wingship study. As a adjunct to this effort, the Naval Surface Weapons Center (White Oak) and the Naval Air Warfare Center, Aircraft Division, Warminster addressed alternative missions which might benefit from the unique technical capabilities of wingship designs. While the NSWC examined potential surface platform roles for such a concept, NAWCADWAR analyzed the potential for its use in traditional or "new" airborne roles. In many cases, such as an amphibious assault, antisubmarine warfare (ASW) or mine warfare, the role distinctions become vague and in such cases were addressed by both groups.

The NAWCADWAR chose an approach which examined the projected capabilities of wingships, determined what benefits these capabilities would have in current mission roles and suggested new roles in which the platforms could be utilized. The overall assessment is both qualitative and quantitative. Analysts familiar with the mission areas were consulted and their inputs incorporated into the study. Previous efforts which examined wing-in-ground effect (WIG) concepts were also utilized.

Section 2.0 of this report is a summary of the characteristic data supplied for five wingship concepts (800 to 5000 ton class). Limited performance data was supplied and the information used is also summarized here. In the examination of a platform designed to fly primarily in-ground effect (IGE) but utilized as a conventional air platform (i.e. to cruise and sometimes loiter at altitude), it is important that the performance capability of that platform in the out-of-ground effect (OGE) regime be known. Detailed OGE performance information was not available for all five of the wingship concepts analyzed. It was therefore necessary to assume certain capabilities when examining the concepts in these roles.

Prior to investigating the use of wingships in alternative air mission roles, it was necessary to examine the potential military benefits of the concepts. Section 3.0 presents an attempt to understand these benefits while also addressing any characteristics of the platforms which could prove detrimental to mission goals.

In Section 4.0 a series of top level examinations of potential naval air missions is presented. For each mission the following is discussed:

- mission description / objective
- background - what is the mission need?
- rationale - for wingship utilization in the mission
- requirements
  - mission
  - platform performance / combat suites / payloads
- current / alternative systems
- observations of wingship utilization

Sections 5.0 and 6.0 present a detailed examination of two mission roles for the wingship concepts, that of an amphibious assault transport and that of a multi-mission (AAW / STW / Surveillance / etc.) offensive / defensive "Big Mother" air platform capable of performing simultaneous or sequential missions.

The conclusions of Section 7.0 are drawn from both qualitative and quantitative analyses. They are based on the expertise of the analysts and technologists in the mission areas, past related studies, requirements, etc. It must be stated here that there was no attempt to insert cost comparisons into the analysis process The study group was developing wingship cost parameters concurrently with this effort which precluded their use in this analysis.

2.0 CONCEPT DEFINITION

This section will provide a definition of "wingship" and try to establish a set of ground rules as to just what the concept is capable / not capable of for analysis purposes.

Basically a wingship is a large aircraft capable of carrying a payload many times greater than today's conventional transports at comparable speeds and with greater efficiency. Combining the characteristics of ships and aircraft, the wingship has the capacity of a ship and the speed of an aircraft. By flying close to the surface of the water (approximately 50 ft.) the designs operate IGE, improving lift while decreasing drag, resulting in a theoretical fuel efficient mode of operation. A Power-Augmented-Ram (PAR) concept, using engine exhaust which is trapped under the fuselage and wings, generates an air cushion support to reduce takeoff power requirements. After takeoff, the wingship transitions from PAR to IGE.

The wingship will have the capability to:

- fly IGE at sea states up to 4 and over level terrain.
- TO and land fully loaded in the water. No ground landing is possible without significantly damaging the wingship. Takeoff from land is impossible with payloads.
- "sea sit" - sit in the water (up to sea state 4) with a substantial amount of stability.
- maneuver on the water (with a draft of 10 - 15 ft.) at low speeds (up to 20 kts.).
- nose-to-shore unload.
- fly OGE for significant periods of time at altitudes approaching 10K ft with the capability to "pop-up" to 20K ft. (This capability has not been agreed upon by technologists for these particular design concepts. Performance information provided for OGE operations is limited).

For the purpose of this analysis five wingship concepts were designated for mission requirements and sizing exercises. The takeoff gross weights ranged from 800 to 5000 tons. Specific information on the concepts' payloads, empty weights and fuel fractions, speeds, ranges and cargo bay dimensions are presented in table 2.1.

Table 2.1: Wingship Mission Analysis Concept Design Points

WINGSHIP CONCEPT	GTOW (TONS)	PAYLOAD FRAC.	EMPTY WEIGHT FRAC	FUEL FRAC	SPEED (KNOTS)	RANGE (NM)	CARGO BAY (W'XH'XL') INTERNAL DIMENSIONS
1	800	0.2	0.44	0.36	330	2900	14' X 19.5' X 126'
2	800	0.3	0.53	0.17	330	900	17' X 22' X 143.5'
3	3000	0.2	0.39	0.41	320	4600	24.4' X 30.4' X 197.6'
4	3000	0.3	0.46	0.24	320	2050	28.4' X 34.75' X 226.25'
5	5000	0.3	0.70	0.40	400	9000	39' X 13.5' X 311' 72' X 19.5' X 316'

The following figures (2.1 to 2.5) represent the limited performance data made available for the wingship concepts at the time of this analysis. They were derived from a Northrop wingship parametric study, reference a., and some later information provided by the mission analysis team. An effort to further define the concepts and the potential performance was still on-going by the team and was not available for this first look into alternative missions.

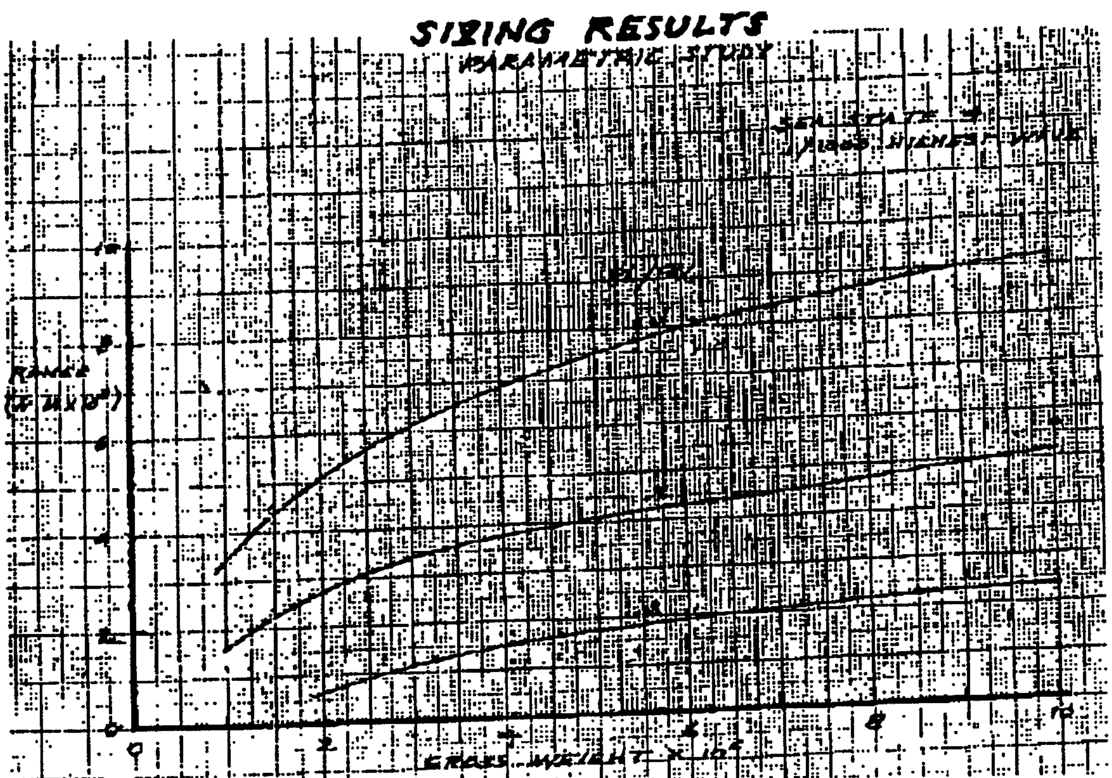

Figure 2.1

CRUISE MACH NUMBER
PARAMETRIC STUDY

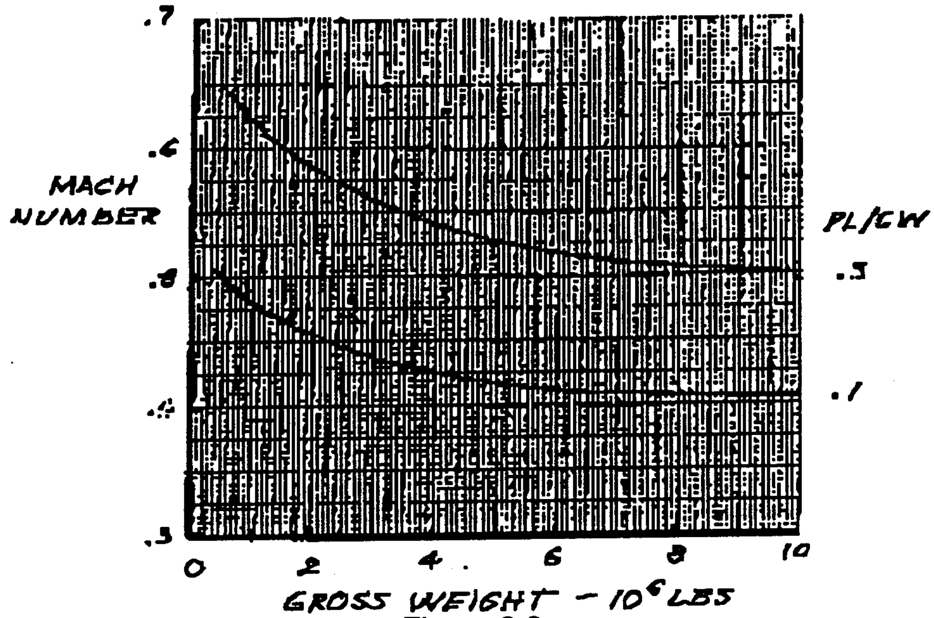

Figure 2.2

ENGINES REQUIRED
PARAMETRIC STUDY

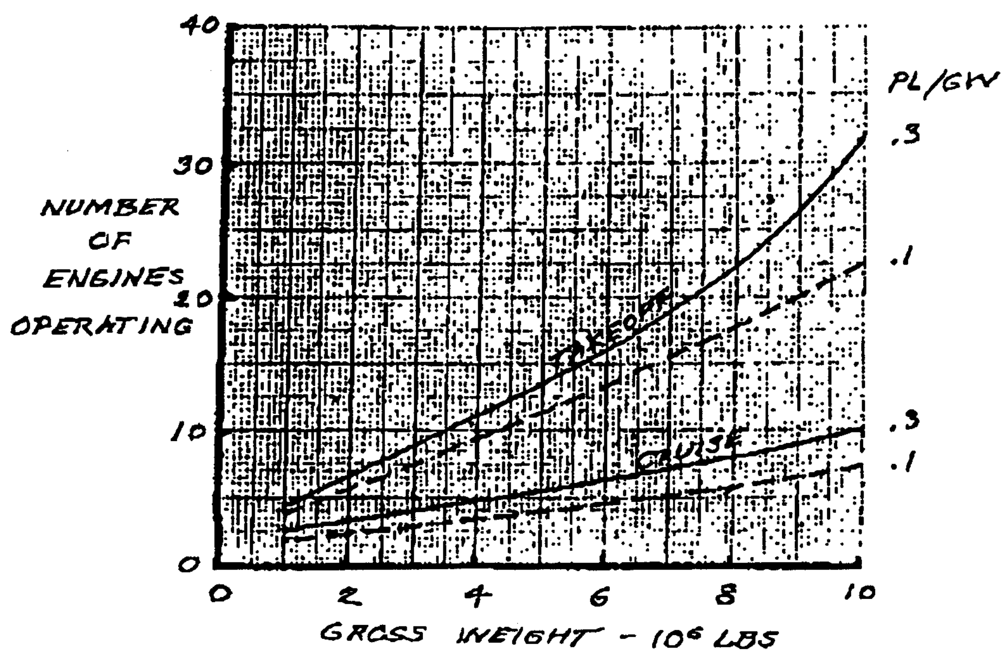

Figure 2.3

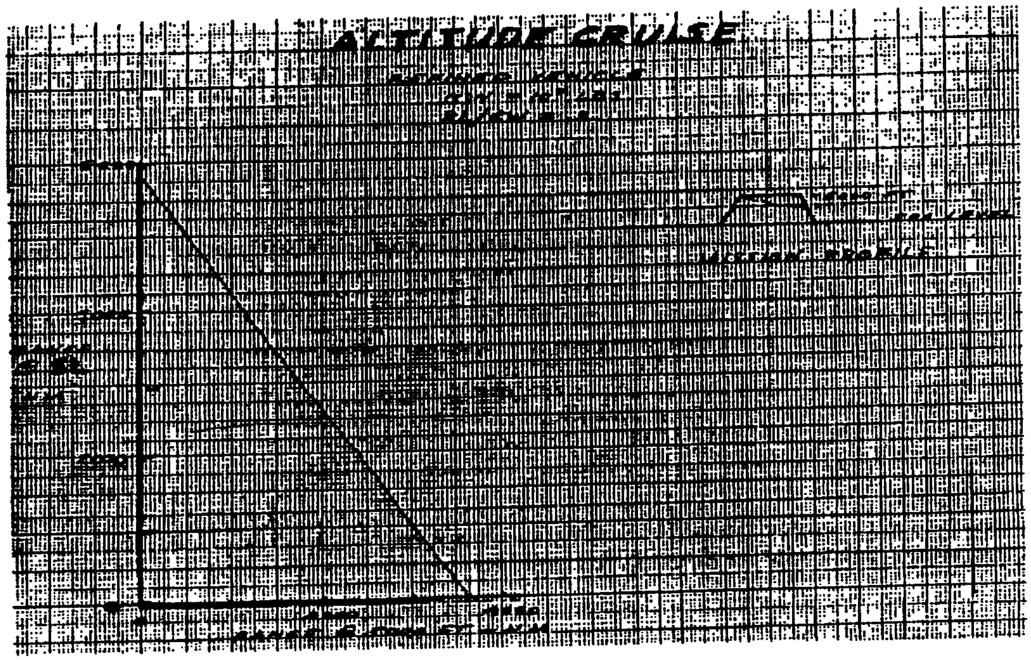

Figure 2.4

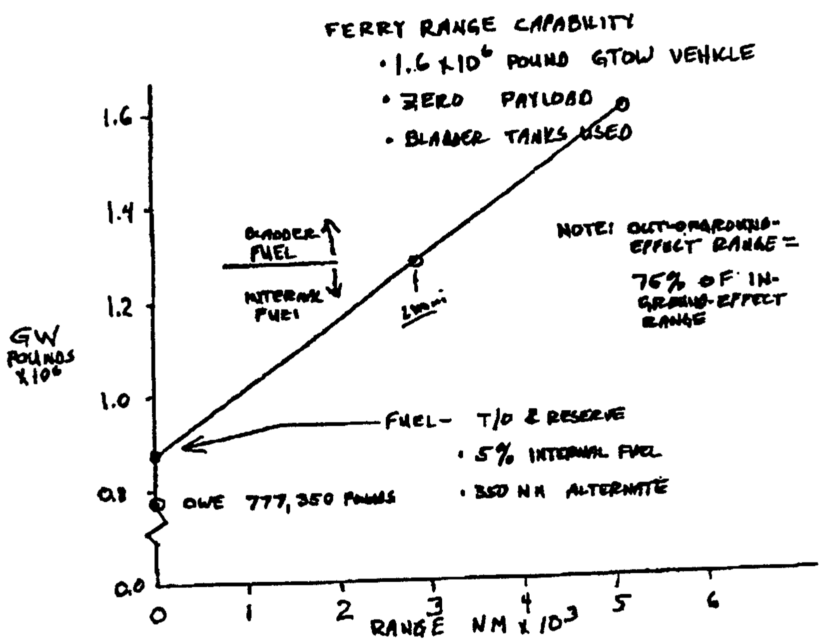

Figure 2.5

3.0 MILITARY VALUE OF THE WINGSHIP CONCEPTS

The primary projected value of a PAR WIG (wingship) is its ability to transport large payloads, long distances at relatively high speeds. There is a theoretical improvement in aerodynamic efficiency of large payload (160 - 1500 ton) wingships operating IGE at significantly higher speeds than platforms which must remain in contact with the water.

This section will summarize and discuss the identified baseline wingship concepts' (Sec 2.0) advantages and disadvantages for utilization in naval air mission roles.

3.1 EFFICIENT PAYLOAD TRANSPORT

Heavy (large) payload, long distance operations, relatively high speed and efficient operational capabilities. These are the most widely identified benefits of a large wingship when compared to conventional combinations of ships / aircraft for moving large amounts of cargo / personnel in a short time (i.e. with minimal warning). It is because of the potential for this capability that the overall wingship analysis was originally undertaken. Utilizing projected performance information supplied by the wingship analysis technical group and Aerocon Inc., the company who designed the concepts (under ARPA contract), this projected efficiency was examined.

It must be stressed here that within the technical arm of the wingship study group, the projected capabilities of the systems are not without some doubters. Questions have arisen as to the actual amount of fuel required for the concepts to leave the surface of the water and reach an efficient cruise condition. Theoretical aerodynamic studies have been conducted for decades with the only "real" data derived from Soviet-built scale models and some operational data from the "Caspian Sea-Monster" in the 1960s. Two wingships, the Orlyanok (154 tons) and the Lun (441 tons) were constructed for military use but no actual operational use has occurred.

The parametric data (Section 2.0) also suggests that as the wingships fly OGE (if indeed this is actually possible for long durations) the efficiency of the craft decreases significantly. This is understandable for the wingships were not designed to fly in this regime, yet it becomes extremely important when considering the concept for use in a naval air role. The additional engines required for takeoff but not used in IGE cruise could be used in powering the platform to altitude. (figure 2.3)

Table 3.1: Aircraft/Wingship Characteristics/Performance

A/C	OPER. GW (k-lb)	PAYLOAD (k-lb)	PAY FRAC	PAYLOAD VOL $(k\text{-}ft)^3$	FUEL (k-lb)	FUEL FRACT	RANGE (nm)	SPEED (kts)	FERRY RANGE (nm)
C-5	769	265	0.34	35	177	0.23	2456	450	6750
C-17	585	160	0.3	38.0	176	0.30	2400	450	4600
KC-130	155	28	0.18		46	0.30	2841	300	4586
KC-135	275.5	87	0.32	5.5	80	0.29	2621	450	7600
C-141	287	134	0.47	6.5	150	0.52	2100	422	6350
P-3	135	20	0.14	4.2	62	0.46	4000	411	4830
WS 800 Ton	1600	320	0.2	34.4	576	0.36	2900	330	~4250
WS 800 Ton	1600	480	0.3	53.7	272	0.17	900	330	~4250
WS 1500 Ton	3000	600	0.2	146.6	1230	0.41	4600	320	
WS 1500 Ton	3000	900	0.3	223.4	720	0.24	2050	320	
WS 5000 Ton	10000	3000	0.3	607.4	4000	0.40	9000	400	19800

Table 3.1 is a comparison of some military aircraft characteristics and performance (references b and c) and those of the five wingship concepts. A cursory look at this data suggests the following:

- the unrefueled ranges of the transport aircraft are comparable to the 800 / 1500 ton wingship designs.
- the fuel efficiencies (ton - miles /fuel) of the aircraft were higher than the 800 ton wingship designs. The efficiencies of the 1500 ton designs are less than that of two aircraft examined (C-5 and KC-135). Information provided for the 5000 ton design showed an efficiency almost double that of a C-5 and triple that of a C-17. Available data shows that the efficiency of the wingships increase as the size of the concept grows. No projections were made beyond a 5000 ton size vehicle.
- the projected wingship cruise speeds are lower than many of the transport aircraft listed. It should be noted that the wingship speeds shown are IGE. No projections of cruise speed at altitude were provided.
- The payload fractions of the aircraft and wingships are similar.
- the wingship designs offer the capability to carry a significantly larger payload (weight and volume) than current or projected military transport aircraft at comparable speeds and distances.

This final capability would seem to make the wingship an ideal candidate when a mission called for a ship-sized cargo to be delivered a significant distance in a short time (a rapid response mode in support of projected rapid movement forces). It would also prove beneficial as a platform for carrying a large weapon (offensive / defensive), sensor and power-generating equipment payload. The system could be capable of

conducting simultaneous / sequential missions without having to refuel, rearm,etc. The range capability of such a platform would allow for almost unlimited basing potential.

3.2 SEA SITTING

The wingship concepts being examined will have the capability to fly over land both OGE and IGE (smooth terrain), but are designed primarily to operate over large bodies of water. They will takeoff from, land and be based on the water. The definition of "sea sitter" is a platform that will be capable of being based at sea (in sea states of 3 /4) for long periods and also be stable enough to conduct operations (load and off load payloads) in these conditions. A large seaplane design of similar size would be able to land on the water but would not be stable in these sea states and would not be considered a sea sitter. The wingship concepts also have an extremely shallow draft (approx. 15 ft.) which would not restrict operations to harbors with the deep channels required by most shipping. The concepts are projected to be maneuverable on the water at about 20 kts.

The obvious advantage to all this is that the wingships will not be restricted to utilizing airfields which must accommodate their large size. There are currently a significant number of runways available to US forces whose dimensions force our large cargo transport fleet to land with a significant payload or fuel penalty. The situation is more critical when considering projections of potential base denials for our aircraft. Another advantage of a sea sitter is that if required it could extend its range through the use of at-sea refueling from shipping assets.

The down side to the "sea-landing-only" aspect of the wingship design is the inability to deliver beyond the beach (other than air drop). Some air missions (USMC inland assault) requiring the transportation of troops / cargo inland could not be accomplished with this restriction. Another factor which must be considered is that there are some areas of the world where coastline geographies make off-loading to a beach impossible. Ports /harbors or a system to transfer (airlift) the cargo / personnel would be required.

3.3 SURVIVABILITY

From a survivability perspective wingship designs exhibit a significant advantage over ships in that while transporting payloads IGE the susceptibility to submarine / mine threats is essentially negated. However, when seasitting or maneuvering on the water these threats must be addressed. Wingship efficiencies and relatively high speeds would allow it to follow circuitous routes to evade perceived threats. Being a sea sitter it can land on the water outside the envelopes of any shore based threat. By flying IGE (low) it will avoid some weapon / sensor systems. Most air missions require the platform to increase its altitude at some point thus negating this low level flight advantage. Section 6.0 examines in detail this aspect of the platforms susceptibility for both "pop-up" and loiter portions of an offensive / defensive air platform mission. In addition the tactical cost of low level flight is examined (optical horizon reduction and associated sensor / weapon use limitations).

4.0 NAVAL AIR WINGSHIP APPLICATIONS

From a naval air mission perspective, the primary wingship evaluation factor has not been fully defined - that is the true operation-at-altitude performance of these large wingship concepts. As has been previously stated, there is only limited theoretical parametric data in existence and limited agreement among technologists as to its viability. In most airborne missions (with the exception of logistics / transport operations) endurance at altitude is a critical requirement for all platforms. However, for this analysis, the information provided was assumed to be accurate and projections were made to complete the data set.

4.1 NAVAL WARFARE TASKS

The following tables (4.1, 4.2) summarize the fundamental and supporting naval, warfare tasks as defined by NWP-1 (ref d). Examination of the potential utilization of the wingships in some of these task areas are presented in the following section.

Table 4.1: Fundamental Naval Warfare Tasks

NAVAL WARFARE TASK	DEFINITION
ANTI-AIR WARFARE (AAW)	The destruction of enemy air platforms and airborne weapons, whether launched from air, surface, subsurface or land platforms. It comprises all the measures that are employed in achieving air superiority.
ANTI-SUBMARINE WARFARE (ASW)	The destruction or neutralization of enemy submarines. The aim of anti-submarine warfare is to deny the enemy the effective use of his submarines.
ANTI-SURFACE-SHIP WARFARE (ASUW)	The destruction or neutralization of enemy surface combatants and merchant ships. Its aim is to deny the enemy the effective use of his surface warships and cargo carrying capacity.
STRIKE WARFARE (STW)	The destruction or neutralization of enemy targets ashore through the use of conventional or nuclear weapons. This includes operating bases from which an enemy is capable of conducting or supporting air, surface or subsurface operations against U.S. or allied forces.
AMPHIBIOUS WARFARE (AMW)	Attacks, launched from the sea by naval forces and by landing forces embarked in ships or craft, designed to achieve a landing on a hostile shore. It includes fire support of troops in contact with enemy forces through the use of close air support or shore bombardment.
MINE WARFARE (MIW)	The use of mines and mine countermeasures. It consists of the control or denial of sea or harbor areas through the laying of minefields and countering enemy mine warfare through the destruction or neutralization of hostile minefields.

Table 4.2: Supporting Naval Warfare Tasks

NAVAL WARFARE TASK	DEFINITION
SPECIAL WARFARE (SW)	Naval operations generally accepted as being non-conventional in nature, in many cases clandestine in character. Special warfare includes special mobile operations, unconventional warfare, coastal and river interdiction, beach and coastal reconnaissance, and certain tactical intelligence operations.
OCEAN SURVEILLANCE (OS)	The systematic observation of ocean areas to detect, locate and classify selected high interest aerospace, surface, and subsurface targets and provide this information to users in a timely manner. A target may be any hostile, neutral or friendly platform of interest. Ocean surveillance provides the current operational setting in which Navy commanders deploy forces to do battle.
INTELLIGENCE (INT)	The assessment and management of information obtained via surveillance, reconnaissance and other means to produce timely indications and warning, location identification, intentions, technical capabilities, and tactics of potential enemies and other countries of interest.
COMMAND, CONTROL & COMMUNICATIONS (C^3)	The overall operational management of the Navy in peace and war. The Navy Command and Control System (NCCS) provides the means to effectively exercise the authority and direction of naval forces in the accomplishment of their mission. It ensures that all Naval command echelons are able to discharge their individual responsibilities by receiving sufficient, accurate and timely information on which to base their decisions and by having available the means to communicate these decisions to the forces involved.
ELECTRONIC WARFARE (EW)	Electronic support for all warfare tasks. Its primary objective is to ensure the effective use of the electromagnetic spectrum by friendly forces while reducing or denying its use to an enemy.
LOGISITICS (LOG)	The re-supply of combat consumables to combatant forces in the theater of operations. It may often be a major factor in determining the success or failure of an operation. A principal aim of naval logistics is to make the operating forces as independent as possible of overseas bases.

4.2 WINGSHIP MISSION APPLICATIONS (TOP LEVEL)

In order to examine the potential use of large wingships in naval air roles, mission analysts familiar with current and projected task requirements were provided a summary of the baseline concept designs (characteristics / performance data) and asked to comment on the platforms' viability in certain mission roles. They were also urged to fully consider how the wingship could fit into the Regional Defense Strategy proposed in the current Defense Planning Guidance (DPG) (reference e). The DPG , which addresses out to 1999 "and beyond", was used as a basis for the determination of mission / need requirements for a mid and far term introduction of the wingships. The DPG seeks

> "...to promote a more stable and democratic world....by adopting a regional focus for our efforts to strengthen cooperative defense arrangements with friendly states and to preclude hostile, nondemocratic powers from dominating regions of the world critical to us. The strategy also aims to raise a further barrier to the rise of a serious global challenge. To accomplish these goals, we must preserve U.S. leadership, maintain leading-edge military capabilities, and enhance collective security among democratic nations. The National Military Strategy reflects these considerations in the force employment and adaptive planning guidance it provides. The regional defense strategy rests on four essential elements:

- Strategic Deterrence and Defense -- a credible strategic nuclear deterrent capability, and strategic defense against limited strikes.

- Forward Presence -- forward deployed or stationed forces (albeit at reduced levels) to strengthen alliances, show our resolve, and dissuade challengers in regions critical to us.

- Crisis Response -- forces and mobility to respond quickly and decisively with a range of options to regional crises of concern to us.

- Reconstitution -- the capability to generate wholly new forces to hedge against renewed global threats."

The following missions were reviewed and potential wingship benefits studied:

- Anti -Submarine Warfare (ASW)
- Force Sustainment
- Aerial Refueling
- Mine Warfare (Offensive)
- Airborne Mine Countermeasures (AMCM)

These initial top level mission investigations seek to identify mission objectives, present background needs discussions, provide a rationale for the potential introduction of the wingship in the mission role, identify mission and platform requirements (including payloads and /or combat suites), identify current or alternative systems and provide final observations as to the overall value of the wingship in this warfare task.

Two other missions were selected for a more extensive examination. These are Amphibious Assault and a multi-mission offensive / defensive weapons platform. These analyses are presented in Sections 5.0 and 6.0 respectively.

Other, more ship-oriented, roles for the wingship such as a Special Operations Force (SOF) carrier, a self-sustaining blockade platform or a large evacuation vehicle were not examined in the effort but should be addressed in the future.

4.2.1 Airborne Anti -Submarine Warfare (ASW)

Mission Area: ASW

Mission Objective: Provide an airborne capability to support the destruction / neutralization of enemy submarines. Detect, locate, classify, track and / or engage submarines in cooperation with other forces and / or with self directed anti-submarine armament.

Background: Anti-submarine warfare protection (carrier task forces, convoys, amphibious task forces) missions include area search, barrier, surveillance support contact investigation and screening. Area search missions are conducted in the open ocean to clear out areas of known or suspected submarine activity. For this mission a moving barrier of adjacent sonobouy fields is planted and monitored by the ASW aircraft. In the barrier mission, ASW barriers are employed primarily for interdiction of enemy submarines across principal transit lanes or for bounding and controlling access to selected ocean areas. Contact investigations are generated by SOSUS, towed array, lost contacts by other ASW tactical units, etc. Screening is the role of providing protection around the task force / convoy as it proceeds forward.

Rationale: The wingship concept characteristics considered to be of benefit to the ASW mission area include long range capability, efficiency, speed and large payload capability.

Requirements: Three basic air platforms provide ASW mission support: land-based long range aircraft, carrier-based conventional aircraft and carrier / amphibious platform-based rotary wing aircraft.

A typical profile for a land based ASW aircraft includes flying out 100 to1500 nm, spending 4 to 6 hours time-on-station (TOS), at altitudes between 5 and 15 K ft. with an occasional drop to 1 - 1.5 K ft. to search for periscopes. Typical TOS for the CV-based aircraft is 4 hours. These two platforms will work in concert with one another based on their capabilities (range, payload and response time) and the nature of the mission. The rotary wing platform adds a dipping sonar capability to the mix. Typically the conventional aircraft may be armed with Anti-Surface-Missiles (ASMs) for "target of opportunity" anti-surface warfare (ASuW) engagements.

A future ASW combat suite may consist of the following:

Sensors:
- sonar receivers (2 or more)
- AN/UYS-2
- MAD
- ESM
- ECM
- FLIR
- RADAR (periscope)
- Dipping Sonar TBD

Armament / deployables*: - > 30 sonobouys
- 10 or more MK-50s
- TBD depth charges
- 10 or more ASMs (for ASuW mission)
- TBD AAMs (self defense)
- UAVs**

* The numbers of armaments / deployables is a direct function of the size of the area to be covered and the potential intensity of the threat. It is in making these determinations that the platform performance (at altitude) must be entered into the equation.

** The potential use of unmanned air vehicles (UAVs) as monitoring platforms at altitude launched from "mother ships" is currently under study and could be applied to this mission area.

<u>Current / Alternative Systems</u>:

Land -based - P-3
Carrier-based - S-3
Helo - H-60

<u>Observations</u>: Although the wingship size would offer a capability to carry more sensors, weapons, fuel, etc., the ASW analysts queried doubted the viability of such a large platform (800 - 5000 ton) in a traditional air ASW role. They stated that air ASW shortfalls were related more to sensor capabilities than air platform capacity or performance. Because much of the mission time for ASW is spent loitering at altitude, the efficiency of the platform in its current wingship configuration was questioned. As sensor capabilities increase (i.e. periscope detection radars, etc.) extended coverage will be possible by increasing air platform loiter altitudes. The ability of the platform to accommodate some self protection while carrying a full sensor / weapon payload is a plus for the wingship. The "Advanced Naval Vehicles Concepts Evaluation (ANVCE) Project (reference f), which examined a series of advanced platforms (surface ships, SESs, WIGs, OGE operating WIGs and "designed-for-loiter" aircraft), concluded that the air ASW mission should be conducted by a platform designed to fly primarily OGE.

4.2.2 Time-Critical At Sea Replenishment

Mission Area: Logistics / Force Sustainment

Mission Objective: The rapid, covert delivery of mission critical supplies, personnel or special munitions to remotely deployed combat units engaged in operations or anticipating operations

Rationale: The wingship could deliver the necessary supplies or personnel rapidly to the forces at sea requiring replenishment by providing post-deployment logistic support at sea or along isolated coastlines without land-bound rendezvous access capabilities (ports, airfields, drop zones) that are necessary for re-supply by ship or transport aircraft. These restrictions would complicate and possibly compromise the mission. Furthermore, because of the considerable payload of the wingship, a small special ops force could have greater than 100 tons of potential supply capacity at its disposal. This could provide some interesting possibilities to operational planners.

Requirements:

Range: > 2500 nm; with one refueling > 5000 nm
Cargo load: supplies, munitions, troops, SDVs, etc.
(Capacity reqt. mission related)
Surface sitter up to sea state 4 (negates seaplane concept)

Current / Alternative Systems: N/A

Observations: The wingship's primary benefit is delivering a large payload, over long distances with transport aircraft speed. When considering SOF or RDF missions, operational planners are often constrained by logistic and mobility considerations. The wingship may provide a solution. Typically small forces with light equipment can move rapidly, but the same force could not employ bulky equipment. This force, supported by the wingship, could employ heavier equipment and greater firepower. Also consider the advantage of at sea replenishment of special munitions or warloads of deployed ships or submarines. The ship or submarine could withdraw from the immediate area of operations to a rendezvous location to receive the cargo from the wingship. The replenished unit can then be rapidly recommitted to operations.

4.2.3 Navy / USMC Air Refueling

Mission Area: Multi

Mission Objective: Provide adequate tanking capability for carrier-based aircraft: duty tanking, Fleet Air Defense (FAD) support and strike support. Provide air refueling during USMC combat and deployment missions.

Background: Current carrier-based tanking is conducted by dedicated tankers supplemented by strike aircraft with buddy stores. Duty tanking involves primarily loitering in the vicinity of the carrier, refueling low state aircraft during recovery and providing fuel for all oncoming fighters. FAD support involves surge tanking to support the FAD fighter combat air patrol (CAP) grids. Strike support involves overhead tanking of a strike group in close proximity to the carrier group.

In the USMC combat support role, the tanker will fly within 50 nm of the forward edge of the battle area (FEBA), loitering at airspeeds compatible with the tactical aircraft, providing the necessary refueling to extend their maximum range, increase their TOS and payload capabilities and increase their operational flexibility. Deployment support includes aerial refueling and navigational support to deploying tactical aircraft.

Rational: The primary advantage of using a wingship as a tanker is the increased tankage capacity based on its large payload capacity. The platform, when not transferring fuel, could sea-sit, thereby opening up valuable deck space on the carrier. The wingship tanker could also be refueled on the water.

Requirements: Currently the flight profile of the duty tanker may take one of three forms: a yo-yo profile, where the tanker launches early, transfers all of its fueling over a short period of time, and lands near the end of the subsequent recovery period; a single cycle profile where the tanker transfers its fuel and lands after one complete deck cycle; and a double cycle profile, where the tanker has sufficient fuel to remain airborne for two complete deck cycles. The profile flown depends on the number of returning aircraft that need fuel, the amount of fuel that they need to make it to the next landing period and whether or not there are one or two duty tankers operating at the same time. Altitude requirements range from SL to 20K ft. with speed requirements of 200 to 250 kts .

The FAD support mission is a surge tanking requirement to support a FAD fighter CAP grid. This grid represents current fleet tactics against high priority air threats, and imposes the greatest demands on the tanker assets. Performance requirements are the same as for duty tanking. Strike support tanking missions generally involve overhead refueling in the vicinity of the carrier or escort tanking of strike group aircraft. Strike support tanking in the vicinity of the carrier is generally not very demanding and can be considered a fallout capability. Strike escort tanking requires the tanker to have cruise / climb performance capabilities comparable with that of the strike group.

USMC combat support and deployment support platforms require cruise compatibility with their tactical aircraft. Combat support requires the tanker to fly within 50 miles of the FEBA, loiter (approx. 2 hrs) at Mach .65 - .7 at 20 - 25K ft. providing maximum fuel. Deployment support provides aerial refueling and navigational support to USMC tactical aircraft deploying out to 3000 nm. The mission altitude called for is within the 30 - 35K ft. band. Mission airspeed is within a range extending from the

maximum endurance airspeed to the maximum range airspeed of the tactical aircraft (Mach .7 at 30K ft.). The deployment support mission also requires a platform compatible with short airfields (4K ft.) with a capability of transporting the unit equipment of a Marine Expeditionary Force (MEF).

Current / Alternative Systems:

- CV tanking - A-6 and or other available strike aircraft using "buddy stores".
- USMC tanking - KC-130s
- USAF tanking - KC-135s / KC-10s

Observations: The potential high capacity wingship aerial tanker for CV aircraft would allow a Battle Group stance further out at sea, providing reduced susceptibility to the forces. While a wingship obviously cannot meet the inland transport requirements of the USMC deployment mission, the increased fuel delivery capacity and comparable range capabilities with current large transports, makes the wingship a viable candidate for refueling. A major key to the acceptance of the wingship in this role will be its OGE altitude / speed capability (compatibility with receiver tactical aircraft). A seaplane option may offer the wingship benefits while meeting the aerodynamic requirements of the mission (including the transport role).

4.2.4 Rapid Offensive Mine Delivery

Mission Area: Mine Warfare

Mission Objective: Provide for the rapid deployment of mines (accurately positioned and armed) before intended targets transit and in view of projected limited air assets.

Background: The requirement for timely mine laying places a burden on the fleet to employ platforms with acceptable capabilities. Operational and environmental factors which drive the vehicle performance requirements include: target type, mine type / numbers, response time, distances from mine stocks to objective area, laying accuracy required, target area topography, threats and required covertness. Each of three delivery platform types (aircraft, ships and submarines) have some unique capabilities which, under different situations, make them the most effective system. No vehicles are configured solely for mine delivery.

Rationale: The wingship capabilities which make it a capable mine layer are its large payload capacity, which could significantly reduce the number of sorties required to sow a field. Individual mines can weigh as much as 2300 lbs. thus taxing air asset numbers to the maximum when large area fields are required. Surface ships offer the advantage of delivering a larger payload of mines than either aircraft or submarines but are susceptible to attack by enemy submarines. High speed above ocean operations of a wingship would resolve this deficiency. The speed of the wingship and its range / endurance combine to make it a capable platform when response time is critical and the distances from the mine stockpile to the objective area are significant. The IGE transit and delivery mode of the wingship would add an element of covertness to the mission achieved only by the limited delivery capability of a submarine.

Requirements: Although no specific requirements are specified for airborne mine delivery (usually a fallout capability for those aircraft available for mine delivery use) the following can apply:

- Range: CONUS to Diego Garcia / Kuwait / Seoul (with one refueling stop if required).
- Speed: To accurately deliver mines an aircraft must be capable of flying 200 to 500 kts at 200 to 500 ft.
- Payload: No total requirement. The more mines carried the less sorties required per minefield.

Current / Alternative Systems: Alternative systems include aircraft, surface platforms, or submarines.

- Aircraft: limited payloads of carrier-based aircraft. Large payload transport systems may not be capable of flying an envelope which would allow for low susceptibility while making accurate deliveries.
- Surface platforms: large capacities / accurate deliveries but its susceptibility would limit it to a defensive mining role.
- Submarines: while covert, limited mine carrying capability and an inability to replenish a minefield once laid.

Observations: A multi-role wingship platform (ASW, ASuW, etc.) might include mine delivery as a potential role in a future of limited aircraft availability (i.e. carrier assets). The combination of speed / payload / endurance would meet potential shortfalls of current operational platforms.

4.2.5 Airborne Mine Countermeasures (AMCM)

Mission Area: Mine Warfare

Mission Objective: Provide a means to timely clear (remove) all mines from an assigned area or to keep the threat of mines to traffic a low as possible. Critical areas of interest include coastal shallows.

Background: The "air" portion of the AMCM mission can be divided into two distinct tasks: the transport of the AMCM squadrons' equipment to the operations area and the actual mine location, identification and clearance. Currently the movement of a typical AMCM squadron (approx. 185 tons) requires seven C-5As and eight C-141s and involves complex off loading and loadings of equipment, sometimes at significant distances from the operation areas (reference h). Time response to the zone is significant and requires adequate warning time. Once set in the clearance area, rotary wing aircraft are the air platforms used in the actual AMCM role.

Rationale: A wingship dedicated to AMCM could be dispatched from CONUS (or a forward base) at relatively high speeds with an entire AMCM squadron, approach the operations area with low level flight covertness and either transfer the assets to conventional at-sea platforms or act as the AMCM squadron base. A large wingship, as a sea sitter, could be utilized as an at-sea base, launching helicopters or the projected Remote-Operated Minecraft Aircushion (ROMAC) (reference i) vehicles to clear the minefield. See Figure 4.1. The wingship itself could be utilized over the shallows using electro-optic scanning to detect mines.

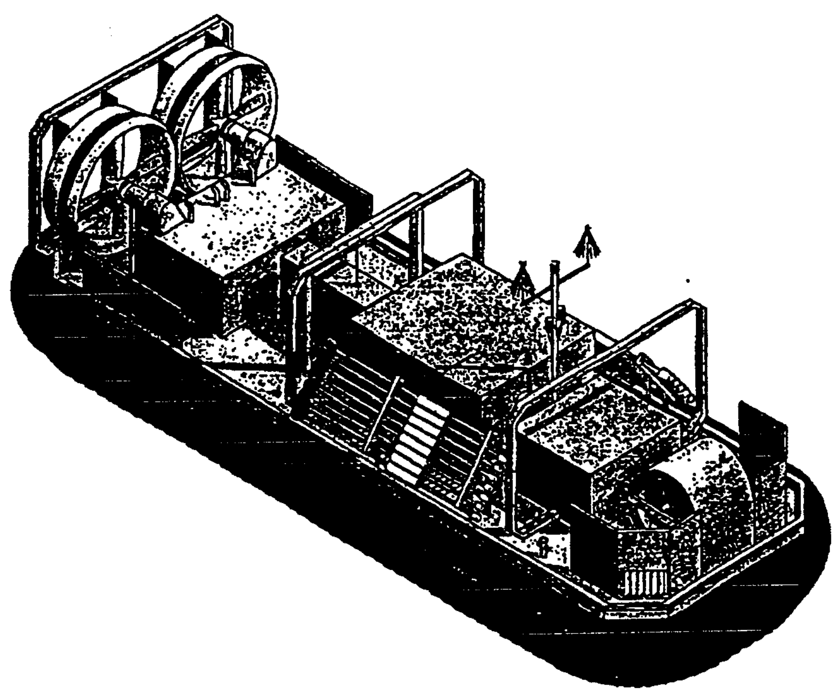

Figure 4.1: REMOTE-OPERATED MINECRAFT AIR CUSHION (ROMAC)

Requirements:

Range: > 5000 nm
Payload: > 185 tons (AMCM Sqd.)
Capabilities: - mine hunting (location / identification sensors)
- mechanical / magnetic / acoustic sweeping

Current / Alternative Systems:

- Current transport assets include C-5s and C-141s

- The MH-53Es and RH-53s are the current airborne assets of the AMCM squadrons. They base on suitable beaches or surface platforms.

Observations: A wingship concept capable of transporting an entire AMCM squadron from CONUS or forward base with relatively high speed to an operational area, sea-sitting outside any threat envelope and immediately beginning operations would be addressing the crisis response element of the regional defense strategy. In addition, this capability would relieve an adverse impact that AMCM operations usually have on the operations of the amphibious platforms or CVs from which they are forced to operate. A large wingship conducting an amphibious assault (see Section 5.0) could also sweep the assault lanes ahead of the amphibious force by utilizing on-board carried helicopters or ROMACs.

5.0 AMPHIBIOUS ASSAULT

The concept of amphibious assault encompasses several missions of various size and techniques, all based on the premise of delivering combat forces from the sea to an area ashore to achieve specific objectives including, but not limited to, establishment of a base for further combat assault against hostile forces. The amphibious assault may be conducted by units ranging in size from a small raid (approximately 100 troops) to a full-scale Marine Expeditionary Force (MEF) (15,00+ troops). The landing zone for the assault may be the shore (beach) or any area further inland using helicopters for troop emplacement. In all cases, convention has the troops delivered to an initial point by ship from which the landing is conducted using various assault vehicles including Landing Craft Air Cushion (LCAC) vehicles, helicopters, Armored Assault Vehicles (AAVs), etc.

The wingship lends itself to amphibious assault by providing another dimension for operational planners. By its nature, the wingship can operate from bases remote from the Amphibious Operations Area (AOA), yet can deliver large quantities of men and material to the AOA in a timely manner. The following paragraphs discuss potential wingship use in Amphibious Assault Operations.

The five wingship conceptual designs were discussed previously. They varied in both size and payload capacity. In order to discuss their applicability for amphibious assault, the size/payload requirements of the different assault operations must be considered. Table 5.1 provides a listing of the unit size including the number of troops and the associated weights and volumes for their equipment. Additional details of specific major equipment will be referenced during subsequent paragraphs as dictated by the mission profile under consideration.

Table 5.1: Amphibious Assault Fingerprints

AMPHIBIOUS ASSAULT FINGERPRINTS

	TROOPS	VEHICLES(KSQFT)	CARGO(KCUFT)	WT(TONS)*
SPECIAL OPERATIONS RAID	170	3	1	41
REINFORCED INFANTRY BATTALION	1,129	25	50	750
MARINE EXPEDITIONARY UINIT	2,800	62	160	1,850
MARINE EXPEDITIONARY BRIGADE	13,500	300	560	7,500
MARINE EXPEDITIONARY FORCE	37,800	870	1,350	22,500

*ESTIMATED BASED ON LCAC TONNAGE CARRIED IN MEU SURFACE ASSAULTS

For the purpose of discussing the use of wingships in Amphibious Assault, several potential operational concepts must be examined. The wingship could be used to transport troops from bases to the AOA for transfer to assault ships at sea. The wingship could also be used for the assault itself, supplementing and/or replacing the assault ships in the operation. If used for the actual assault, the wingship could deliver the force to the beach directly or land amphibious assault vehicles from 25-100 nautical miles offshore.

5.1 TROOP TRANSFER AT SEA

The wingship has a large lift-transport capability lending it to the rapid deployment of troops from a distant training/rear echelon base. The troop transfer at sea mission utilizes both the size of the wingship and its speed advantages over surface combatants.

In this concept, assault troops would remain at their base for training and preparation, either in CONUS or at a forward but rear echelon base such as Diego Garcia in the Indian Ocean. As D-Day approached, the troops would be transported directly from their embarkation point to the assault ships which were prepositioned in proximity to the assault area of operations.

This concept allows the heavy equipment and supplies to be deployed to the regions of conflict well before the actual assault. The assault ships would be positioned off-shore, where required, days, weeks, even months before the operation serving as a show-of-force as well. More than one assault group could be deployed, if necessary, based on the world political situation, the troops themselves would remain at their base (CONUS or forward such as Diego Garcia) for training and rest. As the commitment date approaches, these forces with their personal equipment and perishable supplies would be transported to the waiting amphibious assault group of ships using wingships. Upon arrival the wingships would land at sea near the ships and transfer the troops, etc. to the ships. The assault would then be conducted in a conventional manner.

The advantage of this concept is that the troops would be fresh not having spent weeks or more aboard ship. Their training would be more current. They would be rested. The disadvantages include the complexity / risk of transfer at sea of thousands of troops, and the fact that the training involved equipment other than the actual equipment to be used in combat.

This concept does provide a flexibility for noncommittal of forces to a specific action and an ability to commit them to optional locations as political situations dictate. From that standpoint it is a potentially effective force multiplier.

5.2 DIRECT ASSAULT OPERATIONS

The wingship may be used as the assault vehicle, itself, either by providing a direct step-off platform at the beach or by deploying landing craft at sea. In order to discuss the various operations and requirements, Table 5.2 is included to provide an illustration of the types of equipment//weapons used by the assault forces and their weight and volume imposition on the wingship. Table 5.3 provides similar data on a representative listing of landing craft which could be used to achieve the assault from wingships off-shore.

Table 5.2: Assault Force Heavy Equipment

EQUIPMENT	WEIGHT (TONS)	AREA (SQ FT)
AAV (Armored Assault Vehicle)	30.2	270
HMMWV (Cargo)	4.1	106
(Weapons)	4.8	112
(Ammo)	4.9	112
M923 (3-Ton Truck)	16.8	216
M105A2 (Trailer)	2.8	96
M1A1 (Tank)	67.7	356
LAV (Light Armor Vehicle)	14.6	173
LVS (Logistic Vehicle System)	33.4	332
M198 (155 mm Howitzer)	10.3	382
M923 (5-Ton Truck-Howitzer Tow)	14.4	216
LAV-MEWSS (EW Support)	14.9	178

Table 5.3: Representative Landing Craft

TYPE	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	WEIGHT -LOADED (TONS)
SR7M (Boat)	24	8	3	1250
LCM 6	56	14	4	62
LCM 8	74	21	5	115
LCVP	36	10	4	13.5
LCAC	88	47	10	149.5

5.2.1 Amphibious Raid

The smallest operation which falls under the aegis of amphibious assault is the company-sized raid. This operation is designed to land a unit of approximately 100+ troops to conduct a small scale operation such as destruction of a key hostile fortification or to reconnoiter for future operations, etc. Key to success is stealth and surprise. The assault element due to its size is unprepared for combat against large forces. It must enter hostile territory unobserved, if possible, or at a minimum, observed at the last possible moment such that hostile forces will be unable to be re-deployed against them before the objective is accomplished. This type of operation lends itself to the use of a wingship such as Concept 1. The total payload requirement for this raid is approximately 45-50 tons including 5-6 HMMWVs for rapid ground transport ashore.

The operation would be conducted using a single wingship deployed from a forward base. The wingship would operate directly to the assault AOA and land the assault force at the beach, or would deploy small landing craft capable of carrying the vehicles and troops ashore. The wingship would then depart from the beach and assume a sea-sitting position off-shore beyond range of shore-based weapons until it was time to extract the assault force.

The primary advantage of this concept is the element of surprise afforded by the wingship. At its altitude it avoids land-based sensors, unlike ships which are detectable at similar ranges off-shore but which require significantly longer times to arrive at the AOA. Also of significant benefit, due to the speed of the wingship, is the readiness of

the force. Troops would not have spent long periods aboard ships transiting to the AOA.

Table 5.4: MEB Surface Assault

MEB SURFACE ASSAULT 4 CYCLES, 21 LCAC PER CYCLE, 4 BEACHES						
TIME IN ZONE	LOAD	PURPOSE	LOAD	PURPOSE	LOAD	PURPOSE
1ST CYCLE	RED BEACH		BLUE BEACH		GREEN BEACH	
N-HOUR N-HOUR	1 *AAV 1 *AAV	MCM/AAV SPT MCM/AAV SPT	1 *AAV 1 *AAV	MCM/AAV SUPT MCM/AAV SUPT	1 *AAV 1 *AAV	MCM;AAV SUPT MCM;AAV SUPT
N-HOUR N-HOUR	2 *AAV 2 *AAV	INF CO A INF CO A	2 *AAV 2 *AAV	INF CO B INF CO B	2 *AAV 2 *AAV	INF CO C INF CO C
N-HOUR N-HOUR	3 *AAV 3 *AAV	INF CO A INF CO A	3 *AAV 3 *AAV	INF CO B INF CO B	3 *AAV 3 *AAV	INF CO C INF CO C
N-HOUR N-HOUR	4 *AAV 4 *AAV	INF CO A INF CO A	4 *AAV 4 *AAV	INF CO B INF CO B	4 *AAV 4 *AAV	INF CO C INF CO C
N-HOUR N-HOUR	5 *AAV 5 *AAV	INF CO A INF CO A	5 *AAV 5 *AAV	INF CO B INF CO B	5 *AAV 5 *AAV	INF CO C INF CO C
N-HOUR N-HOUR	6 *AAV 6 *AAV	INF CO A INF CO A	6 *AAV 6 *AAV	INF CO B INF CO B	6 *AAV 6 *AAV	INF CO C INF CO C
N-HOUR N-HOUR	7 *AAV 7 *AAV	INF CO A INF CO A	7 *AAV 7 *AAV	INF CO B INF CO B	7 *AAV 7 *AAV	INF CO C INF CO C
2ND CYCLE	RED BEACH		BLUE BEACH		GREEN BEACH	
H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95	1 *HUMV MK19 1 *HUMV MK19 1 *HUMV MORT 1 *HUMV MORT 1 *HUMV TOW 1 *HUMV TOW 1 *HUMV LAAD 1 *HUMV LAAD 1 HUMV 1 HUMV AMMO 1 HUMV AMMO 1 HUMV AMMO	INF WPNS INF WPNS INF WPNS INF WPNS INF TOW INF TOW INF LAAD INF LAAD CBT ENGR INF H&S INF H&S INF H&S	1 *HUMV MK19 1 *HUMV MK19 1 *HUMV MORT 1 *HUMV MORT 1 *HUMV TOW 1 *HUMV TOW 1 *HUMV TOW 1 *HUMV TOW 1 *HUMV LAAD 1 *HUMV LAAD 1 HUMV AMMO 1 HUMV AMMO	INF WPNS INF WPNS INF WPNS INF WPNS INF TOW INF TOW INF TOW INF TOW INF LAAD INF LAAD INF H&S INF H&S	1 *HUMV MORT 1 *HUMV MORT 1 *HUMV TOW 1 *HUMV TOW 1 *HUMV LAAD 1 *HUMV MK19 1 *HUMV MK19 1 HUMV 1 MRC 1 MRC 1 HUMV AMMO 1 HUMV AMMO	INF WPNS INF WPNS INF TOW INF TOW INF LAAD INF WPNS INF WPNS CBT ENGR INF ENGR INF ENGR INF H&S INF H&S
H+95 H+95 H+95 H+95 H+95	2 *M1A1 2 *HUMV TOW	TK CO PLT 1 INF TOW	2 *AAV 2 *AAV 2 *HUMV TOW 2 *HUMV TOW 2 *HUMV TOW	INF A CMD INF A CMD INF TOW INF TOW INF TOW	2 *AAV 2 *AAV 2 *HUMV MK19 2 *HUMV MK19 2 HUMV AMMO	INF CO D INF CO D INF WPNS INF WPNS INF H&S
H+95 H+95 H+95 H+95 H+95	3 *M1A1 3 *HUMV TOW	TK CO PLT 1 INF TOW	3 *M1A1 3 HUMV AMMO	TK CO PLT 2 INF H&S	3 *AAV 3 *AAV 3 HUMV AMMO 3 HUMV AMMO 3 HUMV AMMO	INF CO D INF CO D INF H&S INF H&S INF H&S
H+95 H+95 H+95 H+95 H+95	4 *M1A1 4 *HUMV TOW	TK CO PLT 1 INF TOW	4 *M1A1 4 HUMV AMMO	TK CO PLT 2 INF H&S	4 *AAV 4 *AAV 4 HUMV AMMO 4 HUMV AMMO 4 HUMV AMMO	INF CO D INF CO D INF H&S INF H&S INF H&S
H+95 H+95 H+95 H+95 H+95	5 *M1A1 5 *HUMV TOW	TK CO PLT 1 INF TOW	5 *M1A1 5 HUMV	TK CO. PLT 2 TK CO.	5 *AAV 5 *AAV 5 HUMV AMMO 5 HUMV AMMO 5 HUMV AMMO	INF CO D INF CO D INF H&S INF H&S INF H&S
H+95 H+95 H+95 H+95	6 *M1A1 6 HUMV AMMO	TK CO CMD INF H&S	6 *M1A1 6 *HUMV TOW	TK CO PLT 2 INF TOW	6 *AAV 6 *AAV 6 MRC 6 MRC	INF CO D INF CO D G/S ARTY G/S ARTY
H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95 H+95	7 *M1A1 7 HUMV AMBL	TK CO CMD INF H&S	7 HUMV AMMO 7 HUMV AMMO 7 *HUMV MORT 7 *HUMV MORT 7 HUMV 7 HUMV 7 MRC 7 MRC 7 MRC 7 MRC 7 HUMV AMMO 7 HUMV AMBL	INF H&S INF H&S INF WPNS INF WPNS INF H&S INF H&S G/S ARTY G/S ARTY G/S ARTY G/S ARTY INF H&S INF H&S	7 *AAV 7 *AAV 7 MRC 7 MRC	INF CO D INF CO D G/S ARTY G/S ARTY

* Indicates lifts used to compute combat power buildup ashore

Table 5.4: MEB Surface Assault (Cont.)

3RD CYCLE	RED BEACH			BLUE BEACH			GREEN BEACH		
H+190	1	*M1A1	TK CO, PLT 3	1	*M198	D/S ARTY	1	*M198	G/S ARTY
H+190	1	MRC	TK CO	1	*M198	D/S ARTY	1	*M198	G/S ARTY
H+190				1	M923	D/S ARTY	1	M923	G/S ARTY
H+190				1	M923	D/S ARTY	1	M923	G/S ARTY
H+190				1	HUMV	D/S ARTY	1	MRC	G/S ARTY
H+190				1	HUMV	D/S ARTY	1	MRC	G/S ARTY
H+190				1	FORKLIFT	D/S ARTY	1	FORKLIFT	G/S ARTY
H+190	2	*M1A1	TK CO, PLT 3	2	*M198	D/S ARTY	2	*M198	G/S ARTY
H+190	2	HUMV	RAD BN	2	*M198	D/S ARTY	2	*M198	G/S ARTY
H+190				2	M923	D/S ARTY	2	M923	G/S ARTY
H+190				2	M923	D/S ARTY	2	M923	G/S ARTY
H+190				2	HUMV	D/S ARTY	2	HUMV	G/S ARTY
H+190				2	HUMV	D/S ARTY	2	HUMV	G/S ARTY
H+190				2	MRC	D/S ARTY	2	HUMV	G/S ARTY
H+190	3	*M1A1	TK CO, PLT 3	3	M923+TRLR FDC	D/S ARTY	3	*M198	G/S ARTY
H+190	3	HUMV	RAD BN	3	M923+TRLR SPLY	D/S ARTY	3	*M198	G/S ARTY
H+190				3	M923+TRLR AMMO	D/S ARTY	3	M923	G/S ARTY
H+190				3	036	D/S ARTY	3	M923	G/S ARTY
H+190							3	HUMV	G/S ARTY
H+190							3	HUMV	G/S ARTY
H+190							3	HUMV	G/S ARTY
H+190	4	*M1A1	TK CO, PLT 3	4	*M198	D/S ARTY	4	M923+TRLR FDC	G/S ARTY
H+190	4	HUMV	RAD BN	4	*M198	D/S ARTY	4	M923+TRLR SPLY	G/S ARTY
H+190				4	M923	D/S ARTY	4	M923+TRLR AMMO	G/S ARTY
H+190				4	M923	D/S ARTY			
H+190				4	HUMV	D/S ARTY			
H+190				4	HUMV	D/S ARTY			
H+190				4	FORKLIFT	D/S ARTY			
H+190	5	M88	TK CO	5	*M198	D/S ARTY	5	M923+TRLR AMMO	G/S ARTY
H+190	5	REWSS	RAD BN	5	*M198	D/S ARTY	5	M923+TRLR AMMO	G/S ARTY
H+190				5	M923	D/S ARTY	5	M923+TRLR AMMO	G/S ARTY
H+190				5	M923	D/S ARTY			
H+190				5	HUMV	D/S ARTY			
H+190				5	HUMV	D/S ARTY			
H+190				5	MRC	D/S ARTY			
H+190	6	AVLB	TK H&S	6	AAV	INF BN CMD	6	AAV	AAV CO
H+190	6	HUMV	RAD BN	6	AAV	INF BN CMD	6	AAV	AAV CO
H+190	6	HUMV	RAD BN	6	REWSS	RAD BN	6	MRC	AAV CO
H+190	6	HUMV	RAD BN				6	HUMV	AAV H&S
H+190	6	HUMV	TK CO				6	HUMV	AAV H&S
H+190	6	HUMV	TK CO						
H+190	6	HUMV	TK CO						
H+190	7	M923+TRLR	TK H&S	7	M923+TRLR FDC	D/S ARTY	7	AAV	AAV CO
H+190	7	M923+TRLR	TK H&S	7	M923+TRLR SPLY	D/S ARTY	7	AAV	AAV CO
H+190	7	M923+TRLR	TK H&S	7	M923+TRLR AMMO	D/S ARTY	7	REWSS	RAD BN
H+190	7	FORKLIFT	CSSE						
H+190	7	HUMV	RAD BN						

4TH CYCLE	RED BEACH			BLUE BEACH			GREEN BEACH		
H+285	1	M923	TK H&S	1	M923+TRLR AMMO	D/S ARTY	1	M923+TRLR	AAV CO
H+285	1	M923	TK H&S	1	M923+TRLR AMMO	D/S ARTY	1	M923	AAV H&S
H+285	1	M923	CSSE	1	M923+TRLR AMMO	D/S ARTY	1	M923	AAV H&S
H+285	1	M923	CSSE	1	HUMV	SRI DET	1	M923	AAV H&S
H+285	1	HUMV AMMO	CSSE	1	HUMV	SRI DET	1	MRC	COMM BN
H+285	1	HUMV AMMO	CSSE						
H+285	2	M923+TRLR	RAD BN	2	M923+TRLR AMMO	D/S ARTY	2	M923	AAV CO
H+285	2	M923+TRLR	RAD BN	2	M923	CSSE	2	M923	AAV CO
H+285	2	M923+TRLR	RAD BN	2	M923	CSSE	2	M923	CSSE
H+285	2	FORKLIFT	CSSE	2	M923	CSSE	2	M923	CSSE
H+285	2	HUMV	CSSE	2	HUMV	SRI DET	2	MRC	COMM BN
H+285							2	MRC	CSSE
H+285	3	M923+TRLR	TK H&S	3	M923+TRLR	SRI DET	3	M923	CSSE
H+285	3	M923	CSSE	3	M923+TRLR	SRI DET	3	M923	CSSE
H+285	3	M923	CSSE	3	M923+TRLR	SRI DET	3	M923	CSSE
H+285	3	MRC	CSSE	3	HUMV	SRI DET	3	M923	CSSE
H+285	3	FORKLIFT	CSSE	3	FORKLIFT	CSSE	3	HUMV	CSSE
H+285	4	M923	CSSE	4	M923+036	D/S ARTY	3	MRC	COMM BN
H+285	4	M923	CSSE	4	M923	CSSE	4	M923	CSSE
H+285	4	M923	CSSE	4	M923	CSSE	4	M923	CSSE
H+285	4	M923	CSSE	4	M923	CSSE	4	M923	CSSE
H+285				4	HUMV	CSSE	4	M923	CSSE
H+285	5	M923	CSSE	5	M923	CSSE	5	M923	CSSE
H+285	5	M923	CSSE	5	M923	CSSE	5	M923	CSSE
H+285	5	M923	CSSE	5	M923	CSSE	5	M923	CSSE
H+285	5	M923	CSSE	5	M923	CSSE	5	M923	CSSE
H+285				5	HUMV	SRI DET			
H+285				5	HUMV	SRI DET			
H+285	6	M923	CSSE	6	M923	CSSE	6	M923	CSSE
H+285	6	M923	CSSE	6	M923	CSSE	6	M923	CSSE
H+285	6	M923	CSSE	6	M923	CSSE	6	M923	CSSE
H+285	6	M923	CSSE	6	M923	CSSE	6	M923	CSSE
H+285				6	MRC	CSSE			
H+285				6	HUMV	CSSE			
H+285	7	LVS	CSSE	7	M923	CSSE	7	M923	CSSE
H+285	7	LVS	TK H&S	7	M923	CSSE	7	M923	CSSE
H+285				7	M923	CSSE	7	M923	CSSE
H+285				7	M923	CSSE	7	M923	CSSE

* Indicates lifts used to compute combat power buildup ashore

5.2.2 Large Scale Operations

Amphibious assaults beyond the raid include battalion-level, MEU (Marine Expeditionary Unit) level, MEB (Marine Expeditionary Brigade) level, and MEF (Marine Expeditionary Force) level operations. In all cases large numbers of troops and heavy weaponry equipment are required. The wingship is amenable to each level but at the MEB and MEF sizes is not an optimal option for conducting the entire operation alone. Both of those operations require large numbers of heavy armor and equipment (An MEF is equal to three MEBs).

An MEB surface assault typically requires the use of as many as 21 LCACs, each of which operates for four cycles from ship to shore to deliver the entire force. Table 5.4 depicts the loadouts of the LCACs for this operation. MEF operations increase the number of LCACs required as well as the number of cycles for each. In addition, a major assault conducted by either an MEB or an MEF would require air cover which would be provided by CV-based aircraft.

The battalion sized assault and the MEU level, however, are amenable to the use of wingships. The battalion level includes 62 armored assault vehicles of various types. These are capable of transport by wingship, each AAV weighing approximately 30 tons, thus fitting both in terms of weight and volumetrically within the wingship payload envelope. Concepts 3, 4, or 5 all provide a capability to conduct battalion operations in reasonable numbers (4 Concept 3, 3 Concept 4, or 2 Concept 5 wingships). The operational concept would require the requisite number of wingship to be loaded at the embarkation base (CONUS for Concept 5, forward for 3 or 4). The wingships would traverse the ocean at best speed consistent with payload/range conditions. They would touch down at the AOA and off-load the assault force at the beach, following which they would either return to base or would take a sea-sitting station off-shore as a back-up for the operation. The wingships thus could deliver the entire battalion and its equipment to the AOA in a timely fashion without a long in-water journey for the force. The assault could occur with minimal warning for the defenders ashore, thus increasing the likelihood of success and minimizing attrition among the assault troops.

The next level of assault is the MEU, an operation requiring more troops that the battalion assault but more significantly, introducing tanks and other heavy armor to the equation. Again, the entire operation could be conducted using wingships, however the numbers would increase due to the tanks, and associated heavy equipment. This operation would utilize 7 Concept 3, 6 Concept 4, or 4 Concept 5 wingships.

A variation to both the battalion and MEU-level assaults would be to deploy the force at sea using various landing craft similar to the LCM 6 and/or LCM 8. If these, or modernized versions, were to be used the numbers of wingships would be increased to compensate. The battalion assault could be conducted using 8 Concept 3, 6 Concept 4 or 3 Concept 5 wingships. The MEU could not use Concept 3 for tasks due to the LCM requirements. It would require 9 Concept 4 or 6 Concept 5 wingships. In all cases, detailed analyses of load factors and specialized equipment for delivering the assault vehicles to the sea need to be examined.

Lastly, as stated earlier, the sheer magnitude, of MEB and MEF assaults would require an inordinate number of wingships to conduct them exclusively without ship borne assets. The wingships, however, could be used to deliver the first elements ashore and to provide a means of continuing re-supply for the forces, both aboard ship and ashore.

6.0 MULTI-MISSION OFFENSIVE/DEFENSIVE WEAPONS PLATFORM (MMODWP)

6.1 DESCRIPTION OF CONCEPT

In this naval air application the wingship serves as a single, multi-mission platform. Referred to as the Multi-Mission Offensive/Defensive Weapons Platform (MMODWP), the wingship takes advantage of its large payload capability and unique operational environment to perform several traditional mission roles, carrying all necessary sensors, weapons and support crew. Such a platform could potentially perform a variety of missions within any warfare area, however, for this analysis the wingship is considered for application within the Strike Warfare (STW) and Anti-Air Warfare (AAW) areas.

In light of the current U.S. military force downsizing there is a definite need to exploit the multi-mission capabilities of both current and future platforms. The ability to deploy a single platform capable of performing varied missions simultaneously and/or sequentially would adequately meet future national defense needs within a limited force structure.

The large payload capability of the proposed wingship vehicle concept provides an ideal environment to simultaneously deploy a varied selection of mission systems.

6.1.1 Strike Warfare Missions

As stated in Table 4.1, Strike Warfare encompasses the destruction or neutralization of enemy targets ashore through the use of conventional or nuclear weapons. This includes operating bases from which an enemy is capable of conducting or supporting air, surface or subsurface operations against U.S., or allied forces. Use of the wingship within the Strike Warfare area involves performing ground surveillance to maintain the current tactical picture for friendly ground forces and simultaneously deploying weapons to destroy critical enemy targets. The primary requirement for wingship success in the STW role is to achieve effective line of sight within the enemy territory to detect and launch against a heavily defended ground target while remaining outside the threat response range.

6.1.2 Anti-Air Warfare Missions

Table 4.1 describes the Anti-Air Warfare mission as the destruction of enemy air platforms and airborne weapons, whether launched from air, surface, subsurface or land platforms. It comprises all the measures that are employed in achieving air superiority. The wingship as a Multi-Mission Offensive/Defensive Weapons Platform would provide missile defense for a small naval Surface Action Group (SAG). In this role the wingship would simultaneously perform ocean surveillance, forward pass of hostile threat tracks, and weapons deployment versus ingressing missiles to provide self defense and well as support of SAG defense operations. Wingship success in the AAW role requires effective line of sight and response time to deploy weapons against enemy air threats ingressing to the SAG.

6.2 ADVANTAGES OF WINGSHIP AS MMODWP

6.2.1 Allowable Payload (Ton_{vol}-Mile/Hr)

The fundamental advantages of a wingship platform stem from the benefits of exploiting aerodynamic ground effect at low flight altitudes. The primary performance

advantage is increased range through efficient cruise operation and larger allowable payloads.

As a Multi-Mission Offensive/Defensive Weapons Platform, the large wingship payloads provide the capability to employ multiple mission critical systems and the necessary support crew on a single platform while maintaining the vital operational range necessary for effective platform deployment.

6.2.2 Sea Sitting Capability

The large surface area of the wingship platform provides a stable, operational sea-sitting capability in high sea states not common among traditional air vehicle platforms. This capability frees the wingship from carrier dependency, and allows for immediate landing over any body of water. This spontaneous landing capability is useful in the event of emergency flight situations and also allows for development of flexible mission profiles with mid-mission refueling performed by in-sea tankers. The sea-sitting mode also provides a method for increasing response time through use of prepositioned wingships near potentially hostile regions.

6.2.3 Survivability

Since the typical operational altitudes of the wingship are well below those of ordinary aircraft, the wingship exhibits a decreased susceptibility to certain threats which are not operational within the wingship IGE altitudes. For the Multi-Mission Offensive/Defensive Weapons Platform, certain ground and air threats are not effective when the wingship is operating at low altitudes. However, to effectively deploy the offensive and defensive weapons required in the STW and AAW missions requires some high altitude operations which can negate any wingship survivability benefits.

6.3 SCENARIOS

The FY 1994 - 1999 Defense Planning Guidance document (reference e) provides a selection of illustrative planning scenarios for use in technical analysis of future naval concepts. Examination of the Major Regional Contingency - East (U) scenario indicated the typical aggressor threat forces and provided a situation summary applicable to this analysis. From this scenario, certain assumptions of both ground and air threats were developed to allow for hypothetical analysis of wingship effectiveness as a Multi-Mission Offensive/Defensive Weapons Platform.

6.4 ANALYSIS OF MISSION EFFECTIVENESS

In this section the wingship effectiveness is quantified when operated in the Strike and Anti-Air Warfare areas. In both cases the analysis is performed to evaluate the wingship capability to satisfy the appropriate success criteria.

6.4.1 Strike Warfare Analysis

As stated previously, the wingship success in STW requires effective line of sight within the enemy territory to detect and launch against a heavily defended ground target while remaining outside threat response range. The radar line of sight is a function of the radar altitude and target altitude making the wingship operational altitude the primary measure of effectiveness.

The hypothetical STW scenario depicted in figure 6.1 is considered. This analysis assumes the wingship ground surveillance mission is to provide the complete ground tactical picture to friendly ground forces securing a forward line on an enemy beach front. The weapons deployment mission requires the wingship to avoid enemy

surface to air missile (SAM) sites while maintaining sufficient line of sight to detect and launch versus the enemy target.

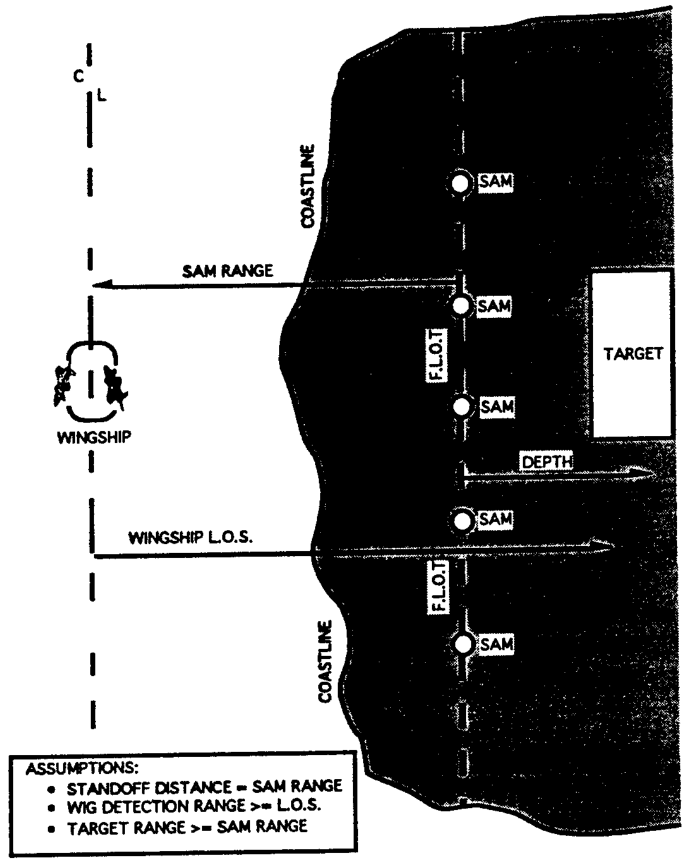

Figure 6.1: MMODWP STW Analysis Scenario

The STW scenario assumes the wingship standoff distance is driven by the maximum SAM launch range. The wingship radar detection range is assumed to be greater than the radar line of sight. Therefore, if the wingship can "see" the target the radar is assumed to detect it. The target is considered to be located behind the SAM defensive line at sea-level altitude. The SAM defensive line is located in a worst case position, on the Forward Line Own Troops (FLOT) and assumed to be located at sea-level altitude.

6.4.1.1 Strike Warfare Analysis Results

The results indicate that the wingship minimum effective altitude is directly linked to SAM threat type and performance. Wingship IGE effectiveness for both missions in this STW analysis is unsatisfactory compared to present platform capabilities. For detailed, quantitative results of this analysis refer to reference k, "Wingship Multi-Role Offensive/Defensive Weapons Platform Effectiveness" (U).

6.4.2 Anti-Air Warfare Analysis

As stated previously, the wingship success in AAW requires effective line of sight and response time to deploy weapons against ingressing enemy air threats. The available response time is dependent upon the distance at which the ingressing missile is first detected, thus prompting a need for an effective wingship line of sight. Again the

radar line of sight is a function of the radar altitude and target altitude, making the wingship operational altitude the primary measure of effectiveness.

The hypothetical AAW scenario depicted in figure 6.2 is considered. This scenario assumes the wingship ocean surveillance mission is to provide the complete tactical picture to the SAG group and supporting platforms. The attack mission requires the wingship to detect the ingressing enemy missiles, acquire, launch and destroy prior to enemy intercept of friendly forces.

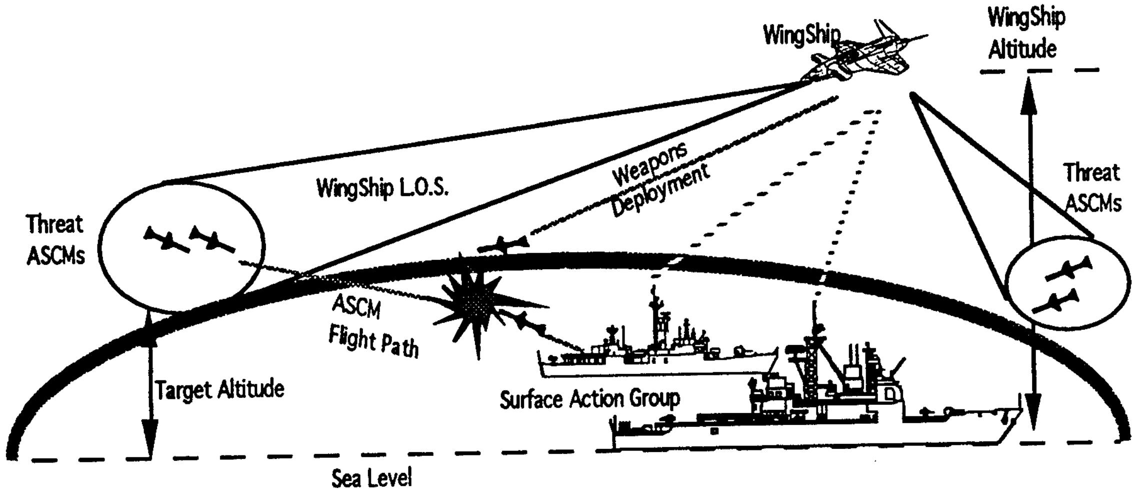

Figure 6.2: MMODWP AAW Analysis Scenario

The initial analysis performed for the MMODWP AAW role involved examining the platform effectiveness as shown in figure 6.3. This initial stage of the analysis assumes the wingship is supporting the SAG against many ingressing enemy Air to Surface Cruise Missiles (ASCMs). The wingship provides necessary SAG defense support. Since the threat in this case involves many ASCMs, the SAG defenses are assumed to be fully saturated and the wingship will address any threat not handled by the SAG. The overall effectiveness of the wingship in this AAW case hinges upon the wingship line of sight providing enough advanced detection time to allow deployment of an air to air missile and intercept of an ASCM before that ASCM enters within the minimum SAG SAM intercept range.

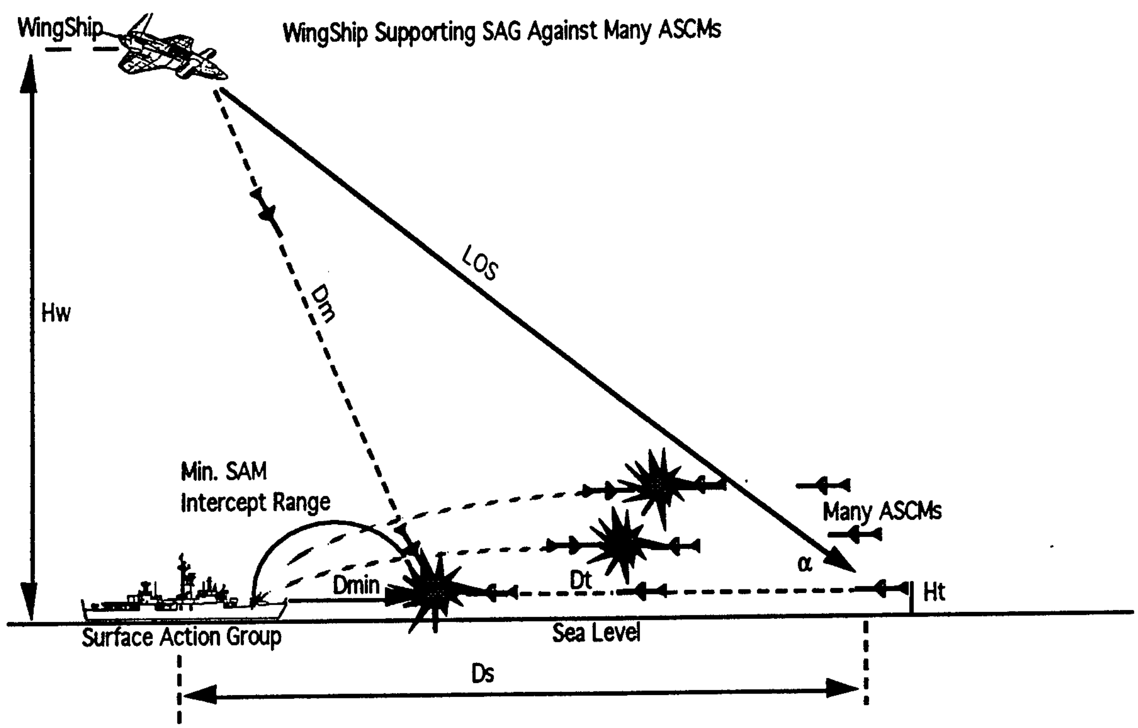

Figure 6.3: Initial AAW Analysis - Wingship Supporting SAG

Extending the analysis performed above, the wingship was considered for use as an ASCM defense platform supplementing the SAG ASCM defense, depicted in figure 6.4. This case assumes the threat includes only a few ASCMs and the wingship provides complete threat defense for the SAG. In this case the wingship effectiveness depends on its capability to detect the ASCMs at such a distance that adequate response time exists to deploy an air to air missile and intercept the entire enemy threat beyond the SAG line of sight. This provides depth of fire previously unavailable to the SAG from its own defenses.

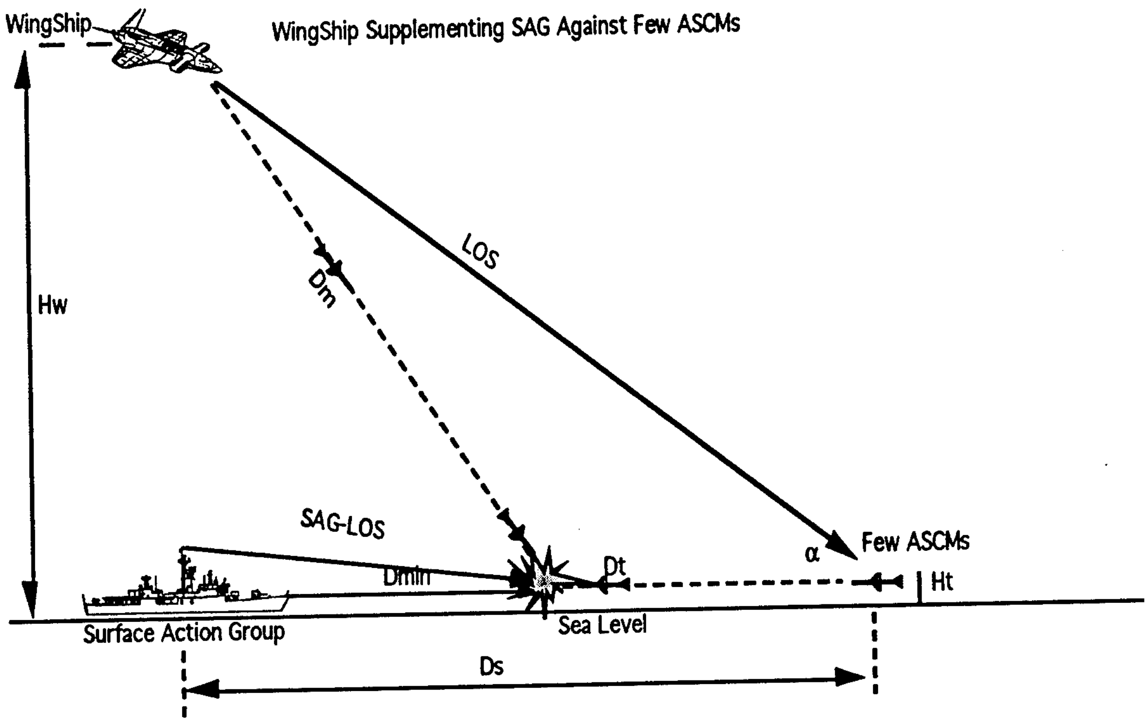

Figure 6.4: Extended AAW Analysis - Wingship Supplementing SAG

6.4.2.1 Anti-Air Warfare Analysis Results

The analysis indicates that the wingship can potentially contribute to SAG defensive operations by providing improved depth of fire and superior surveillance capabilities. However, the effectiveness of the MMODWP in AAW is dependent upon wingship operational altitude. For detailed, quantitative results of this analysis refer to the reference k, "Wingship Multi-Role Offensive/Defensive Weapons Platform Effectiveness" (U).

6.5 POTENTIAL WINGSHIP LOADOUTS

The wingship has the capability to carry a diverse selection of sensor and weapons systems, making it a promising candidate for the multi-role environment envisioned in the MMODWP. Potential payload loadouts include an array of future capability air to air and air to surface missile weapon systems. Table 6.1 lists a hypothetical projected payload breakout for the 800 ton wingship concept. It is important to realize that the data in the table is preliminary and could vary radically depending upon specific mission requirements, wingship performance variations and future sensor and weapon system developments.

Table 6.1: Wingship Concept 1 Payload Breakout

System Description	Item Weight (kg)	Item Weight (lbs)	Qty	Total System Weight (lbs)	WingShip Payload Available (lb)
AGM84A Harpoon	530	1168	30	35053	284947
AGM84E Slam	630	1389	30	41667	243280
AGM65F Maverick	307	677	30	20304	222976
AGM88 Harm	361	796	30	23876	199100
AIM 120 AMRAAM	157	346	30	10384	188716
AIM-7 Sparrow	230	507	30	15212	173504
AIM-9R Sidewinder	87	192	30	5754	167750
AIM-54C Phoenix	454	1001	30	30027	137724
Flight Avionics		5000	1	5000	132724
Surveillance Radar		8000	4	32000	100724
Illuminator Radar		3000	3	9000	91724
IRST & FLIR		400	5	2000	89724
Laser Radar		625	5	3125	86599
Navigation		1000	1	1000	85599
Displays & Controls		10000	1	10000	75599
Processing Equip.		2000	10	20000	55599
J-STARS					55599
S.A.R.		150	1	150	55449
G.S.M.s		10000	1	10000	45449
Crew		200	20	4000	41449
Supplies		20000	1	20000	21449
Misc.		20000	1	20000	1449

It is clear from the payload analysis that the 800 ton, Concept 1 wingship could carry a wide array of sensors and weapons necessary to serve as a MMODW platform. The larger wingship concepts provide substantial payload capability with extensive room for growth. While the payload capabilities of the wingship concepts do not appear to limit its application as a MMODW platform, the potential degradation in maneuverability should be considered. The present analysis does not include consideration of wingship maneuverability. As the concepts are further defined, follow-on analysis should address this issue.

6.6 NEARLY SIMULTANEOUS/SEQUENTIAL OPERATIONS

Since the Multi-Mission Offensive/Defensive Weapons Platform is inherently capable of performing multiple missions it is well suited to supporting nearly simultaneous/sequential operations. The simultaneous mission functions have been addressed in the STW and AAW analyses discussed above. For both warfare areas the wingship performed surveillance and attack/missile defense missions simultaneously.

Sequential operations implies the ability to effectively employ a platform in two separate, distinct hostile regions, generally within the same contingency area. Application of the Multi-Mission Offensive/Defensive Weapons Platform for sequential operations requires investigation of potential wingship endurance and operational ranges. The sequential operations assumes the wingship will operate in the STW role in a given hostile environment, supporting operations of friendly ground forces.

Following the STW operation the wingship will immediately transition to an AAW role in a separate hostile environment without refueling or basing. The current wingship performance data is inadequate to effectively estimate potential endurance. Quantitative analysis of the MMODWP in sequential operations will require enhanced definition of the wingship capabilities.

6.7 CURRENT SYSTEMS

The advantage of the wingship as a Multi-Mission Offensive/Defensive Weapons platform is its ability to perform simultaneous/sequential missions normally fulfilled by multiple aircraft. Those aircraft are thus free to concentrate on other missions, further supporting the need for nearly simultaneous/sequential operations.

Examination of current operational Naval platforms provides an indication of present day single role platform capabilities. The current Navy platforms which perform the missions proposed for the MMODWP include;

F-14 Tomcat:	Air-Air Superiority
F/A -18 Hornet:	Fighter/Attack
A-6E Intruder:	Attack
P-3 Orion:	Maritime Patrol

6.8 MULTI-ROLE VS. SINGLE-ROLE PLATFORM COMPARISONS

Qualitative comparison of the wingship as a multi-role platform with a present day single role platform indicates the potential enhancements and shortfalls of this technology.

Table 6.2: Multi-Role vs. Single Role Platform

WINGSHIP CONCEPT MULTI-ROLE PLATFORM	CONVENTIONAL AIRCRAFT SINGLE-ROLE PLATFORM
Not dependent on basing	Require adequate land basing or carrier support
Potentially large coverage capability (endurance)	Refueling more feasible, provides competitive endurance
Greater variety sensors/weapons (large volume)	Aircraft volume/payload restricted
Less vulnerable (low flight altitude, defensive weapons capability)	Less capable of defensive weapons due to volume/payload restrictions
Simultaneous mission capable	Lacks simultaneous capability
Travel to other areas with full complement (NS - Fuel Efficiency)	Typically single scenario limited
Altitude limited	Greater altitude capability - designed for OGE operation
Single platform operation	Multiple platform operations

6.9 OBSERVATIONS

Success of the wingship in this mission depends primarily on the maximum operational altitude and time at altitude capabilities of the vehicle. Aircraft design personnel expressed concern that the particular concepts used as design points are derivatives of Russian WIG designs which were not intended to fly at altitude. Issues such as

pressurization, buffet boundaries and maneuverability were raised. New designs must be considered with the effect on volumetric capacity, sea-sitting capabilities and survivability examined.

7.0 CONCLUSIONS

This top level examination of potential alternative military missions for wingships revealed the following:

- A major military application for future large wingships might be in amphibious assault: remote troop delivery or assault platform roles. Major benefits of the former include the delivery of fresh and currently trained troops to pre-positioned cargo-loaded assault platforms. Multiple situations could be better addressed in this mode. As an amphibious assault base, a wingship could also conduct direct assault operations of a raid, battalion or unit level. The platform could provide for a direct step-off at the beach or deploy landing craft / helos at sea. The sheer magnitude of MEB / MEF operations would require an inordinate number of wingships to conduct exclusive operations without combining with ship borne assets. Timing and flexibility are key elements in the recommendation of wingship utilization in the amphibious roles.

- For airborne missions (as opposed to cargo / troop movement) significant portions of the mission are required to be flown at altitudes ranging from 10 to 30 K ft., sometimes just "popping up" and sometimes loitering for hours. These requirements would most certainly reduce the perceived benefits of the "design point" wingship concepts (endurance / payload).

  In the case of the multi-role wingship concept, STW role, the limited minimum effective altitude is directly linked to SAM threat type and performance. The concept's effectiveness is limited compared to current platform capabilities. In the AAW role, the wingship can potentially contribute to SAG defense operations by providing improved depth of fire and surveillance capabilities but success is dependent on wingship operational capabilities.

  In order to quantitatively assess the value of the concept in these roles, it is critical that the analysts have a better (more realistic) handle on wingship OGE performance. The CNO Advanced Naval Vehicles Concepts Evaluation Project , conducted in the late 70's (reference f), concluded that a WIG concept which spends more than "occasional" time OGE would be better served designed as a seaplane or pure aircraft. Later design studies have shown that hybrid WIGs may also provide a solution.

- A primary characteristic of the wingship is its restriction to water takeoffs and landings and its ability to sea-sit. This capability combined with the low draft and in-water maneuverability of the platform, bodes well in a potential future of airfield or harbor denial. However this benefit must somehow be compared to the cost of not being able to transport and land with payloads inland (i.e. USMC deployment transport / refueling mission). This, once again, points to the need to examine seaplanes / hybrids / amphibians as alternative to pure wingships.

- Many analysts suggested that a smaller wingship might be a better fit in their mission areas. However, all design information points to a significant lessening in beneficial value as the overall size of the concept decreases:
  - less endurance (less payload)
  - decreased IGE flight capability (lower maximum sea state)
  - reduced seasitting capability

- A critical examination of the value of the concepts' response to a decreased-warning-time situation is not only important for the heavy lift mission role but also for alternative military applications. This would be in accordance with the crisis response element of the regional defense strategy.

- The results of the overall assessment shows potential for large wingship concepts in roles which are mostly "transport oriented". These include amphibious assault transport, at-sea replenishment / force sustainment and mine warfare (could be combined with amphibious assault). Wingship designs for this analysis cannot be considered for airborne (OGE) roles until agreed-upon performance information is made available.

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MTMCTEA REPORT OA 93-4g-48

WINGSHIP

DEPLOYABILITY ANALYSIS

March 1994

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PURPOSE AND SCOPE

The Wingship is a wing-in-ground surface effect vessel proposed by its developer, Aerocon, Incorporated. It is capable of high speed, heavy-lift, transoceanic flight and can potentially fill future strategic transport requirements for rapid force projection into crises around the world. Congress has mandated that a mission analysis effort be conducted to explore the potential of Wingship technology. DOD's Advanced Research Projects Agency (ARPA) has been tasked with conducting the overall mission analysis effort, which encompasses three specific areas: cost analysis, deployability analysis, and other military applications. The Carderock Division, Naval Surface Warfare Center (CD, NSWC), as coordinator of the mission analysis effort for ARPA, has requested MTMCTEA examine the value of the Wingship as a strategic transport asset for deployment of Army forces in selected joint scenarios.

The main objective of the deployability analysis is to compare force closure time and defense transportation asset requirements associated with the movement of various Army units on different transport assets. This analysis examines intertheater movement of five contrasting notional Army forces using four different transport asset mixes: current transport assets, transport assets expected to be fielded in the year 2005, and two separate designs of the Wingship, 1725-ton payload design by Aerocon Inc., and a 900-ton payload design by Northrop Corporation. When determining force closure times, we first looked at the most cost effective force closure using the minimum number of allocated resources to attain closure within a realistic latest arrival date (LAD) at the air or sea port of debarkation. We then looked at the best case force closure using an optimum number of allocated resources to attain closure within accelerated latest arrival dates at the air or sea port of debarkation. These force closure times were then compared to determine the viability of the Wingship as a future strategic transport asset.

FINDINGS

1. One Aerocon Wingship can move an equal amount of Army unit equipment as 15 to 20 C-5 aircraft. One Northrop Wingship can move the same equipment as 6 to 9 C-5s or 9 to 12 C-17s. Cruising at 400 knots, either Wingship can travel as quickly as strategic aircraft.

2. Only 9 Aerocon Wingships or 28 Northrop Wingships are required to transport an equal amount of unit equipment as one large medium-speed RORO (LMSR) ship. Since the Wingship cruise speed is nearly 17 times faster than the LMSR, one Aerocon Wingship is about twice as productive, over time, as one LMSR. One Northrop Wingship is about 60 percent as productive as one LMSR.

TABLE EX-1
WINGSHIP FORCE CLOSURE COMPARISON
FOR FIVE SCENARIOS

Scenario	Current Air and Sea Assets	2005 Air and Sea Assets	Aerocon Wingship	Northrop Wingship
Corps to SWA (LAD-C+30) Best Case Most Economical	C+39	C+31	C+12 (63) C+30 (23)	C+17(102) C+29(59)
Two Division Force to NEA (LAD-C+20) Best Case Most Economical	C+34	C+27	C+5 (65) C+19 (13)	C+10 (109) C+19 (40)
Separate Mechanized Bgde to Caribbean (LAD-C+10) Best Case Most Economical	C+11	C+09	C+01 (16) C+08 (2)	C+01 (36) C+09 (3)
10K Early Entry Force to SWA (LAD-C+20) Best Case Most Economical	C+20	C+16	C+02 (31) C+19 (4)	C+02 (82) C+20 (11)
2K Early Entry Force to SWA (LAD-C+10) Best Case Most Economical	C+09	C+06	C+02 (12) C+08 (3)	C+02 (31) C+10 (8)
Note: Number of Wingships required to achieve stated closure time are shown in Parenthesis.				

3. Table EX-1 summarizes force closure comparisons for five scenarios, clearly illustrating the enormous potential capability of the Wingship. Closure times shown represent the time required for strategic delivery of Army forces (sustainment is not included). Best case closure times represent the earliest closure time for each force when fully utilizing all allocated transport resources of a particular asset mix. Most economical closure times represent the most cost effective use of allocated resources while still attempting to meet latest arrival dates.

a. Deployment of a small corps (3 combat divisions and a light armored cavalry regiment) to SWA by the latest arrival date (LAD) of C+30 can be accomplished by 23 Aerocon Wingships or 59 Northrop Wingships. A fleet of 63 Aerocon Wingships could deliver the corps by C+12 (less than one-third the time of current assets).

b. Deployment of a two-division force (airborne and mechanized) to NEA by the LAD of C+20 can be accomplished by 13 Aerocon Wingships or 40 Northrop Wingships. A fleet of 65 Aerocon Wingships could deliver this force by C+05.

c. Deployment of a separate mechanized brigade to the Caribbean by the LAD of C+10 can be accomplished by 2 Aerocon Wingships or 3 Northrop Wingships. A fleet of 16 Aerocon Wingships or 36 Northrop Wingships could deliver the brigade by C+01.

d. Deployment of TRADOC's conceptual "10K" early entry force to SWA by the LAD of C+20 can be accomplished by 4 Aerocon Wingships or 11 Northrop Wingships. A fleet of 31 Aerocon Wingships could deliver this force by C+02.

e. Deployment of TRADOC's conceptual "2K" early entry force to SWA by the LAD of C+10 can be accomplished by 3 Aerocon Wingships or 8 Northrop Wingships. A fleet of only 12 Aerocon Wingships or 31 Northrop Wingships could deliver this force by C+02.

4. The Wingships tend to fill the cargo "square-foot" capacity sooner than the STON cargo capacity is utilized. Average payload ranged from 54 to 99 percent of capacity for the Aerocon Wingship and 40 to 84 percent of capacity for the Northrop Wingship.

5. The troop capacity for the large Wingship is much too high at 2,000. The highest average passenger count for the 1725-ton Wingship was 465 per Wingship when loading the 2K force. This results in a large amount of wasted troop space that could be better utilized if converted to cargo space.

RECOMMENDATIONS

1. Based on the enormous potential value the Wingship can add to the capability of the DTS, it is highly recommended that the Wingship project proceed to the next phase and that further, more detailed analysis be conducted on this very capable transport design.

2. An increase in cargo "square foot" capacity will increase average payload for the Aerocon Wingship and may result in decreasing Wingship sortie requirements, further improving force closure times for the five forces. This might be best achieved by reducing the troop capacity of the Aerocon design from 2,000 to 500 and converting the saved space into additional cargo deck space.

I. INTRODUCTION

As the 20th century comes to an end, it has become apparent that our current fleet of strategic air transports, the C-5 and especially the C-141, are fast approaching the end of their service lives. The C-17, seen as the replacement for the C-141, has experienced problems which may result in a reduction of the total procurement to as few as 40 aircraft. Also, as shown during Operation Desert Shield, our defense transportation sealift assets are incapable, in some possible scenarios, of delivering a credible-sized force rapidly enough to deter aggression of a sizable enemy threat. Our military strategy has evolved from combating a single predictable Soviet threat to deterring various emerging regional threats requiring the capability to rapidly deploy sizable, lethal forces to counter these emerging threats in all corners of the world. This is becoming increasingly more difficult as our defense transportation system's air assets become less capable.

One possible long-term solution to our increasing inability to quickly react to military crises around the world is the Wingship. Initial development of the Wingship in the United States has been led by Aerocon Incorporated of Arlington Virginia. As envisioned by its preliminary design, the Wingship is a huge, 5,000-ton aircraft capable of carrying a payload of 1,725 short tons, traveling at 400 knots and with a range of up to 10,000 nautical miles. The Wingship's cruising altitude is between 20 to 100 feet above the sea. The Wingship exploits surface effect aerodynamics allowing its high speed, heavy-lift transoceanic capability.

MTMCTEA assistance was requested by DOD's Advanced Research Projects Agency to examine the value of the Wingship as a strategic transport asset for deployment of Army forces in selected joint scenarios. Our assistance and analysis effort supports a mission analysis team initiative coordinated by the Carderock Division, Naval Surface Warfare Center (NSWC) to determine if there is a military mission that can best be filled by the Wingship. In addition to the Aerocon design, a second, smaller Wingship design, developed by the Northrop Corporation, will also be analyzed as part of this study.

MTMCTEA conducted deployability analysis to compare force closure time and defense transportation asset requirements associated with the movement of various Army units on different transport assets. This analysis examines intertheater movement of five contrasting notional Army forces commencing at notional sea/airports of embarkation (S/APOEs) and ending at notional sea/airports of debarkation (S/APODs). These five forces are:

A. A notional corps consisting of three divisions, an ACR, and various corps support units.
B. A two division force consisting of a mechanized division and an airborne division.
C. A separate mechanized brigade.
D. The Army Training and Doctrine Command's (TRADOC) conceptual early- entry 10K force, and
E. TRADOC's conceptual early-entry 2K force.

II. METHODOLOGY

A. GENERAL

TEA possesses an extensive collection of origin-to-destination databases and analytical tools to conduct deployability analysis. This capability describes all components of the origin-to-destination intermodal defense transportation system (DTS), including these transport assets: C-141, C-17 and C-5 aircraft, fast sealift ships, large medium-speed RORO ships and other airlift and sealift. TEA utilized a number of these analytical tools and databases, defined in the following paragraphs, to conduct deployability analysis for this Wingship study.

B. TARGET

MTMCTEA's Transportability Analysis Reports Generator (TARGET) unit deployability model provides an automated way to merge unit equipment authorization data from TRADOC's Table of Organization and Equipment (TOE) Master File with the equipment item data from the Army Forces Command's Equipment Characteristics File (ECF). The TARGET programs, written and designed by MTMCTEA, can determine the unit deployment data required for strategic mobility planning. MTMCTEA analysts used TARGET to generate unit deployment data (personnel strength , vehicle quantity, square feet, short tons), and air sortie requirements for the five separate forces. We modeled the Wingship as an "aircraft" in TARGET to determine the number of Wingships required to transport Army forces. Unit deployment data provided by TARGET was also used to determine sealift requirements for the same five forces.

C. CODES

The Computerized Deployment System (CODES) is the Army's automated ship-stow planning system to improve the accuracy and speed of ship-stow planning. We modeled the Wingship as a "ship" in CODES to analyze and illustrate how Army cargo would be loaded in it. CODES automated ship-loading programs require various data files prior to beginning the system. Once the particular ship to be loaded has been identified, a master ship disk containing ship's deck drawings, characteristics data and trim and stability programming is loaded into CODES. Another file uploaded into the system is the cargo list and cargo characteristics of the unit equipment to be loaded. Other factors such as levels of ballast and amount of consumable liquids in the ships tanks are also required for accuracy. Once all data requirements have been supplied, CODES calculates the stow plan of the particular ship.

At the end of this process, CODES has selected a stow location (compartment) for each piece of equipment. At this point, the CODES graphic capability can be used to plan precise stow of each deck. This is accomplished by placing a template or icon of each piece of equipment, destined for a particular compartment, onto a template of the deck of that compartment on the computer screen until all pieces of equipment have been "stowed". These deck templates can then be plotted on paper as deck drawings and used for actual ship loading.

D. JFAST

The Joint Flow and Analysis System for Transportation (JFAST) is an automated system developed for the US Transportation Command for use in strategic deployment planning. We used JFAST to predict changes in force closure time for Army units resulting from employment of the Wingship. JFAST is used to allocate available strategic lift assets to the movement requirements specified in a particular Time-Phased Force and Deployment Data (TPFDD) plan and creates shipments by air sortie and sealift. JFAST schedules movements based on the most cost effective mode of transportation (i.e. sealift vice aircraft) as long as it can deliver cargo before the latest arrival date (LAD). JFAST then estimates shipment arrival dates to the theater air and sea ports of debarkation (A/SPOD) based on lift capabilities. The system provides force closure profiles to the A/SPODs that are based on the detailed capabilities and constraints of strategic movement assets and theater infrastructure.

III. ANALYSIS

A. WINGSHIP CHARACTERISTICS

TEA used two different Wingship designs with a total of three different payload capacities during the course of our analysis. The larger Wingship is the Aerocon DASH 1.6 design. The DASH 1.6 is a 566 foot long Wingship which has a total gross weight of 5,000 short tons. The smaller Wingship is the Northrop design which has a total gross weight of 3,000 short tons. This design will be analyzed with two different cargo capacities (600 and 900 short tons) which vary due to differences in the fuel capacity of each. The larger fuel capacity of the design with the smaller cargo capacity allows for a more than double operational range capability. Table 1 lists the dimensions, payload capability, and ranges for each Wingship analyzed.

TABLE 1
WINGSHIP DESIGN CHARACTERISTICS

Wingship Design	Payload Capacity STON	Cargo Capacity (SqFt)	Mission Range (NM)	Passenger Capacity	Cruising Speed Knots
Aerocon DASH 1.6	1,725	34,881	8,000	2,000	400
Northrop	900	12,851	2,050	300	400
Northrop	600	9,642	4,600	300	400

The Aerocon DASH 1.6 design's cargo decks are illustrated in figures 1 and 2 showing two different views of the decks loaded with various unit equipment.

B. FORCE DESIGN AND DEPLOYMENT DATA SUMMARIES

1. Force Design

The forces used throughout our analysis were obtained from various sources.

a. Notional Corps. The corps was tailored from an existing notional corps developed by the TRADOC Analysis Center (TRAC) for campaign analysis in a SWA scenario. Appendix A lists all combat, combat support (CS), and combat service support (CSS) units in the notional corps and their unit deployment data. It includes three combat divisions and an ACR, which is somewhat smaller than the contingency corps of 5 and 1/3 divisions which has a 75-day deployment goal under the Army Strategic Mobility Program (ASMP). The non-divisional (CS and CSS) forces in this corps are only about 50 percent the size of the combat divisions, which is much smaller than the 200 percent seen in some plans and studies.

b. Two Division Force. The two division force containing a mechanized division and an airborne division was tailored from existing units in the October 1993 TRADOC TOE. Appendix B lists all units contained in these two divisions and their unit deployment data.

c. Separate Mechanized Brigade. The separate mechanized brigade was taken directly from the October 1993 TRADOC TOE. Appendix C lists all units contained in this brigade and their unit deployment data.

d. 10K Force. The 10K force was taken from MTMCTEA Report BL 93-2, 10K Force Deployability Analysis, published in August 1993 by TEA's Battle Lab Team. The 10K force, designed by TRADOC, is a tailored future early-entry force about the size (in STON) of an airborne (air assault) division with some modifications and enhancements. Appendix D lists all units contained in the 10K force and their unit deployment data.

e. 2K Force. The 2K force was taken from MTMCTEA Report BL 93-1, Light Early Entry Deep Strike (LEEDS) Deployability Analysis, published in September 1993 by TEA's Battle Lab Team. The LEEDS force, designed by TRADOC, is a tailored early-entry force about one-half the size (in STON) of an infantry (airborne) division. Appendix E lists all units contained in the 2K force and their unit deployment data.

2. Deployment Data

Table 2 shows the force deployment data totals generated by TARGET for each of the five forces used in this analysis. A standard combat load consisting of accompanying supplies and ammunition has been included with each force's totals (1 day of supply for class V; 5 days of supply for classes I, IV, and VI; and 15 days of supply for classes II, III, VIII, and IX materials). For purposes of this study, sustainment requirements were not included in force deployment data.

TABLE 2
FORCE DEPLOYMENT DATA SUMMARY

Forces	Personnel Strength	Equipment Total SqFt	Equipment Total STON	Equipment Total MTON
Notional Corps	75,328	5,943,701	367,225	1,139,824
Mech/Airborne Divisions	30,915	2,277,618	131,920	414,033
Separate Mech Brigade	4,345	351,704	26,567	69,900
Notional 10K Force	11,218	798,813	31,776	143,311
Notional 2K Force	5,472	331,781	11,347	50,664

C. SCENARIOS

1. Regional Conflicts

In order to conduct a complete and realistic comparison of the effectiveness of the Wingship as a strategic transport asset, it was necessary to simulate intertheater movement of five contrasting Army units in the JFAST model using various scenarios. This study examined strategic deployment of five notional Army forces within the following respective scenarios:

a. Deployment of a corps size force to Southwest Asia in a high-intensity conflict.

b. Deployment of a two division size force to Northeast Asia in a mid-intensity conflict.

c. Deployment of a heavy brigade to the Caribbean in a low-intensity conflict.

d. Deployment of the Army's conceptual early entry follow-on "10K" force to Southwest Asia in a mid-intensity conflict.

e. Deployment of the Army's conceptual early entry "2K" division ready brigade to Southwest Asia in a mid-intensity conflict.

2. JFAST Requirements

The primary "requirements file" input to JFAST is called the time-phased force and deployment data (TPFDD) or list (TPFDL). We used JFAST's "notional requirements generator" to develop unclassified TPFDDs for each of the scenarios. JFAST TPFDD requirements include all combat support, combat service support, sustainment and ammunition requirements for each scenario. As in all actual deployments, JFAST limits the number of transport assets allocated to each service in a simulated deployment based on required delivery dates in the TPFDD and available transport assets.

D. TRANSPORTATION FACTORS AND ASSUMPTIONS

As directed by NSWC, the intent of this analysis is to give the Wingship concept a very optimistic examination to understand its full potential. In keeping with this intention and to simplify the analysis, the following assumptions and factors will be used:

1. Wingship RORO loading rates:

a. 2,218 SQFT per hour.
b. 12 pieces per hour.
c. 175 STON per hour.

2. Wingship Load/Discharge Times:

a. 1,725T payload - 12 hour load/5 hour discharge times.
b. 900T payload - 6 hour load/4 hour discharge times.
c. 600T payload - 5 hour load/3 hour discharge times.

3. Operational Assumptions:

a. All loading/discharge operations will be straight stern Roll-on/Roll-off.
b. Vessels are Mediterranean moored (stern to pier) at berth.
c. No special materials handling equipment is required.
d. There are no port entry restrictions.
e. Hydrostatic, trim and stability, and center of gravity conditions are not considered.
f. A 75 % stow factor will be used to load the Wingship.
g. Vessels do not refuel at the SPOD while discharging cargo but make a refueling stop on the return trip to the SPOE.
h. Three hours are required for refueling.
i. Vessels follow standard sailing routes (Military Sealift Command "Sail" Model).
j. No delays or lost time are experienced at canals.
k. Berth length requirements: 370 feet including clearance between Wingships.
l. The Wingship is in a ready status near its SPOE.
m. Weather conditions do not effect operation or routing of the Wingship.
n. Near perfect reliability and maintainability are displayed by the Wingship.
o. Adequate warning time is provided to allow loading of forces to commence at the SPOE on C day.
p. No threat of any kind exists along the mission route of the Wingship.
q. Necessary ramps and adequate cargo hatches are onboard without any weight or area penalty.
r. Adequate port berthing is available to allow continuous loading/unloading of cargo on/from all sealift, including the Wingship

E. DEPLOYMENT ANALYSIS

1. General

Our study will encompass three specific areas of analysis to determine the effectiveness of the Wingship when employed as a strategic transport asset. First, CODES was utilized to determine the feasibility of stowing various unit equipment on the cargo decks as designed. Second, we simulated loading of each force on the various DTS transport assets, including the Wingship, using the TARGET air loading model. We then compared sortie requirements of the various air and sea transport assets with sortie requirements of the three Wingship configurations.

Finally, we used JFAST to simulate intertheater movement of each force using current and future mixes of DTS transports to determine base case force closure times. We then added the Wingship to the mix of future DTS transports to compare force closure times with and without the Wingship.

2. Air Sortie Requirements

Air sortie requirements to deploy each force using various air transport assets were calculated using the air load model subsystem of TARGET. Air sortie requirements were calculated for two purposes. First, a comparison of air sortie requirements of the various aircraft, including the Wingship, provide a good indication of the effectiveness of each air transport asset. Also, air sortie requirements were generated to calculate average payload for each aircraft. This data was then fed into the JFAST model as a planning factor to allow for accurate loading of aircraft in JFAST. Existing air transport assets used in this analysis are listed at table 3 with the corresponding payload capacity, range, and current or projected (2005) inventory of each.

TABLE 3
EXISTING TRANSPORT AIRCRAFT CHARACTERISTICS

Transport Aircraft	Payload Capacity STON	Cargo Capacity (SqFt)	Aircraft Range	Passenger Capacity	Current/2005 Inventory
C-141	25	840	3,000	22	234/50
C-5	75	2,186	3,000	73	109/109
C-17	65	1,211	3,000	102	12/102

a. Cargo Aircraft. Table 4 shows air sortie requirements to deploy the five different forces using various air transport assets. Table 4 also shows average payloads, in STONs, for each of the transport options. As this table illustrates, one large (1725T) Wingship can move an equal amount of a notional corps' unit equipment as 20 C-5 aircraft. The **ratio** is the same for the two division force and for the mech brigade, but decreases for the two light forces; 16 C-5s to 1 Wingship to move the 10K force and 15 C-5s to 1 Wingship to move the 2K force. The ratios are smaller when comparing the two smaller Wingships to the C-5 (6 to 9 C-5s to 1 900-ton Wingship and 4.5 to 6.5 C-5s to 1 600-ton Wingship). The **ratios** are even greater when comparing the C-17 with the large Wingship; 25 C-17s to 1 Wingship to move the notional corps, the two division force or the 10K force, 24 C-17s to 1 Wingship to move the Mech brigade, and 23 C-17s to 1 Wingship to move the 2K force.

An analysis of average payloads reveals the C-141, C-17 and C-5 have a much higher payload capacity (STON) utilization rate than the Wingships. The C-141 averaged between 94 and 100 percent utilization of its cargo payload capacity, the C-17 averaged between 66 and 90 percent cargo capacity utilization, and the C-5 averaged between 84 and 98 percent. The 600-ton Wingship averaged between 51 and 83 percent cargo capacity utilization, the 900-ton Winghship averaged between 44 and 72 percent cargo capacity utilization and the 1725-ton Wingship averaged between 59 and 88 percent. The Wingships tend to fill the cargo "square-foot" capacity much sooner than the STON cargo capacity is utilized.

The troop capacity for the large Wingship is much too high at 2,000. The highest average passenger count for the 1725-ton Wingship was 465 per Wingship when loading the 2K force. This results in a large amount of wasted troop space that could be better utilized if converted to cargo space.

TABLE 4
STRATEGIC AIR TRANSPORT SORTIE REQUIREMENTS

Forces	C-141/C-5 Mix	C-17 Only	C-5 Only	600 TON Wingship	900 TON Wingship	1725 TON Wingship
Notional Corps sorties avg load (STON)	7,863/2,410 25/74	6,554 54	5,236 72	801 472	596 635	258 1,467
Mech/Airborne Divs sorties avg load (STON)	2,902/878 24/74	2,473 56	1,937 71	311 439	240 569	97 1,408
Separate Mech Bgde sorties avg load (STON)	480/215 24/75	402 58	247 74	55 496	42 648	18 1,512
Notional 10K Force sorties avg load (STON)	1,221/52 24/74	772 43	499 68	102 328	82 408	31 1,080
Notional 2K Force sorties avg load (STON)	467/12 24/74	272 45	181 63	40 304	31 393	12 1,014

b. Passenger Aircraft. During national emergencies and major regional contingencies, as was experienced in Operation Desert Shield, expanded civil augmentation of military airlift may be required. This augmentation is filled by aircraft in the Civil Reserve Air Fleet (CRAF). The air sortie requirements shown in table 4 do not include air sortie requirements to deploy those residual passengers unable to fit on aircraft sorties shown in this table for the C-141/C-5 mix and the C-5 only. The C-17 and all three Wingships were able to fly all personnel on the sorties shown in table 4. See tables 1 and 3 for Wingship/aircraft passenger capacity while in a cargo carrying configuration. TARGET generates air sorties by first loading each aircraft with unit equipment until the aircraft reaches maximum cargo capacity (short tons or square feet) and then loads passengers to capacity if there is additional weight capacity remaining. Table 5 shows CRAF sortie requirements to deploy residual personnel. These sorties must be added to those in table 4 to get an accurate picture of total sortie requirements to deploy the various forces. The average passenger capability of the CRAF aircraft utilized in this analysis is 274.

TABLE 5
CRAF PASSENGER TRANSPORT SORTIE REQUIREMENTS

Forces	C-141/C-5 Mix	C-5 Only
National Corps	181	70
Mech/Airborne Divisions	87	13
Separate Mech Brigade		9
National 10K Force	23	
National 2K Force	13	1

c. Stow Factor Revision. As previously discussed, TARGET does not use a set stow factor to simulate equipment loading on aircraft but calculates space required to secure each piece of equipment to the deck of the aircraft and makes allowances for this "clear" space. In order to conform with the assumptions provided, table 6 shows revised air sortie requirements for the three Wingship configurations using a 75 percent stow factor. Also shown are average cargo payloads in STONs for each of the Wingships. As illustrated by this table, sortie requirements tend to decrease when using the 75 percent stow factor while loading the large Wingship, especially for the two largest forces. This results in higher STON cargo payload utilization rates than was shown using TARGET generated air sortie data in table 4. However, sortie requirements tend to increase while loading the two smaller Wingship configurations. This results in lower cargo utilization rates than was shown using TARGET generated air sortie data. In any case, sortie requirements for the three Wingship configurations are drastically lower than sortie requirements for the C-5 and C-17. Average payloads remain well below Wingship capacities in all cases.

TABLE 6
WINGSHIP SORTIE REQUIREMENTS
(75 % STOW FACTOR)

Forces	600 Ton Wingship sorties/avg payload	900 Ton Wingship sorties/avg payload	1725 Ton Wingship sorties/avg payload
Notional Corps	822/461 STON	617/614 STON	227/1668 STON
Mech/Airborne Divisions	315/434	236/579	90/1518
Separate Mech Brigade	48/567	36/756	16/1701
Notional 10K Force	110/304	83/403	31/1079
Notional 2K Force	46/265	34/358	13/936

3. Shipping Requirements

Sealift requirements were calculated by dividing the available square feet of stowage area (after stow factor) of each type ship into the total square feet of each force's unit equipment to determine the total number of ships required to deploy a particular force. Sea transport assets used in this analysis, including the 1725-ton Wingship, are listed in table 7 with their corresponding cargo capacity and vessel characteristics. A comparison of sealift requirements to deploy each of the forces in this study using the various types of ships, including the 1725-ton Wingship, are shown at table 8. The Wingship requirements shown here are identical to those shown in table 6 (calculated using 75% stow factor). As illustrated by this comparison, it requires approximately five Wingships to transport an equal amount of each force's unit equipment as one notional Roll-on/Roll-off (RORO) ship.

TABLE 7
SEA TRANSPORT ASSET CHARACTERISTICS

Ship Type	Cargo Dead-weight LTON	Usable Cargo Capacity (SqFt)[1]	TEU Capacity	Current/ 2005 Inventory[3]	Speed (knots)
FSS	25,500	149,868	188	8/0	27
LMSR	24,700	269,000	180	0/19	24
Average RORO	20,000	122,000	367	48/?	19
Average Breakbulk	9,500	48,000	-	76/?	19
Average Container	21,000	-	1,534	92/?	21
Wingship - 1725-Ton	1,540	26,161	162/77[2]	0/?	400

1 This is capacity after 75% stow factor
2 The Wingship can transport 162 TEUs at an average weight of 10.65 STON/container or 77 TEU at the maximum weight of 22.4 STON/container.
3 Ship inventories include MSC, Ready Reserve Fleet and all commercial military-useful, US flag cargo vessels.

Legend:
TEU - 20-ft container equivalent unit. LMSR - Large Medium-Speed RORO.
FSS - Fast Sealift Ship

TABLE 8
SEALIFT TRANSPORT REQUIREMENTS

Forces	FSS[1]	LMSR[2]	Notional RORO	Breakbulk	1725 Ton Wingship
Notional Corps	40	25	49	123	227
Mech/Airborne Division	14	10	19	49	90
Separate Mech Brigade	2.3	1.4	3	8	16
Notional 10K Force	5	3.3	7	17	31
Notional 2K Force	2.2	1.4	3	7	13

[1]Only 8 Fast Sealift Ships (FSS) are in service. These ships will be retired approximately 2005.
[2]Only 19 Large Medium-Speed RORO (LMSR) ships are being procured. Delivery is scheduled between 1995-2002.

4. Wingship Stow Planning (CODES)

The Army's Computerized Deployment System (CODES) was used to simulate loading of selected forces on the Wingship. Our purpose in using CODES for stow planning was to validate the accuracy of Wingship air sortie requirements generated by TARGET. We also desired to illustrate how a heavy force might be stowed on each of the Wingship configurations to ensure the feasibility of stowing various unit equipment. Using the cargo deck dimensions, payload capacities, and other characteristic data provided by the two developers, each Wingship was built into the CODES model. We then chose two forces, the separate mechanized brigade and a tank battalion, to conduct our stow planning analysis. Due to time constraints, trim and stability (center of gravity) data was not used during CODES loading of the Wingships. If follow-on analysis is required, given ample time, this capability can be included.

a. Mechanized Brigade. First we loaded unit equipment of the separate mechanized brigade on the Aerocon Inc. Wingship design (1725-ton payload). Appendix F contains template drawings showing actual placement of all unit equipment of the brigade on each of the Wingships required to deploy this force. CODES required 15 Wingships to load the brigade's unit equipment, as compared to the 18 required by TARGET. This also compares to the 16 Wingships required when using a standard 75 percent stow factor. CODES exceeded the maximum payload capacity by an average 46 STON when loading the 1725-ton Wingship. This clearly validates the use of the 75 % stow factor, which was used to simulate Wingship deployment in JFAST, as a viable estimator of Wingship requirements.

b. Tank Battalion. We then loaded unit equipment of a tank battalion on each of the three different Wingship configurations. Appendix G contains template drawings showing actual placement of the tank battalion's unit equipment on each of the 1725-ton payload Wingships required to deploy it. Appendix H contains similar template drawings showing the 900-ton payload Wingship and appendix I contains template drawings showing the 600-ton payload Wingship.

5. Force Closure Simulation Using JFAST

a. DTS Transport Assets Used. Force closure profiles for deployment of the five forces were first generated in the JFAST model using the current inventory of DTS transport assets to establish baseline closure profiles. Current DTS transport assets are: C-141, C-5, Fast Sealift ships, notional RORO ships, and other sealift ships (as shown in tables 3 and 7). Force closure profiles were then generated in JFAST for the five forces using DTS transport assets expected to be available in the year 2005 to establish a second baseline. 2005 DTS transport assets used are: C-17, C-5, Large Medium-Speed ROROs (LMSR), and other sealift ships. Force closure profiles were then generated in JFAST adding the Aerocon Wingship design to the 2005 transport mix. For the purposes of this study, LMSRs and all RORO ships were excluded from this mix to allow the JFAST model to choose the Wingship as the exclusive RORO asset. Finally, force closure profiles were generated using the Northrop Wingship design (900 STON cargo capacity) in place of the Aerocon Wingship. The JFAST model determined the number of the allocated assets actually used within a particular scenario, dependent upon the size of the force to deploy and the criticality of the scenario. In all scenarios, the number of Aerocon Wingships allocated for use was 65 and the maximum number of Northrop Wingships allocated for use was 120.

Please note that JFAST uses optimistic planning factors for C-141 and C-5 airlift simulation, resulting in rapid closure times. These planning factors (for aircraft utilization rates, average payload, and number of aircraft available) were not achieved during Operation Desert Shield, resulting in airlift productivity less than 50 percent of those predicted by JFAST. Excursions with more conservative planning factors would result in much later closure times for airlifted units than those shown in the following analysis.

b. Scenarios. Three deployment scenarios (SWA, NEA, and Caribbean) were used to simulate deployment of the five forces analyzed. Within each deployment simulation, latest arrival dates (LAD) were chosen to fully utilize current and 2005 asset mix allocated transport resources, allowing good force closure profile comparisons between the different transport asset mixes. In other words, we assigned LADs to force JFAST into moving cargo as quickly as possible with the available transport assets.

The same LADs were used to simulate deployment using the Wingships, resulting in under utilization of those allocated. However, this provided the opportunity to determine the number of Wingships needed to close the forces at the same time as fully utilized current and 2005 asset mixes. Earlier LADs were then assigned for additional simulations to determine how quickly the Wingship could close the various forces and how many would be required.

c. Force Design. The forces developed in JFAST were built in the notional requirements generator (NRG) and designed to approximate the same forces used in the earlier TARGET analysis. However, the notional corps and two division forces built in the NRG for use in force closure analysis are slightly larger than those forces used in TARGET analysis. The increase in the size of these two forces was due to the generation by the NRG of an additional layer of theater/corps support. As the analyses conducted in TARGET and JFAST were looked at separately, the difference in the size of the two forces does not influence overall findings.

d. Force Closure - Notional Corps. Deployment of a notional corps to SWA was simulated in JFAST using an LAD (at the A/SPOD) of C+30 using all four asset mixes. Force closure profiles generated are shown in table 9. Included in this table are actual number of Wingships and total sorties required. The air assault division is the first unit to close in all cases. Closure of this division was attained by use of current air assets by C+10. It also closed at C+10 using 2005 air assets. Closure of this division was significantly accelerated using either of the Wingships in the asset mix, closing on C+04 with the Aerocon Wingship, and C+05 with the Northrop Wingship.. Current assets closed the entire force in C+39, while 2005 assets closed the total force in C+31. The Wingship alternatives are quite effective in closing the total force by C+30. With the Aerocon Wingship replacing all RORO ships, the force was closed in C+30 and required only 23 Aerocon Wingships or on C+29 with 59 Northrop Wingships. Closure profiles of the notional corps are illustrated in figure 3.

TABLE 9
FORCE CLOSURE - NOTIONAL CORPS WITH LAD OF C+30

DTS MIX	AIR ASSAULT DIV CLOSES	TOTAL FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
CURRENT ASSETS	C+08	C+39		
YEAR 2005 ASSETS	C+08	C+31		
2005 ASSETS WITH (1725T) AEROCON WINGSHIP	C+04	C+30	23	311
2005 ASSETS WITH (900T) NORTHROP WINGSHIP	C+05	C+29	59	708

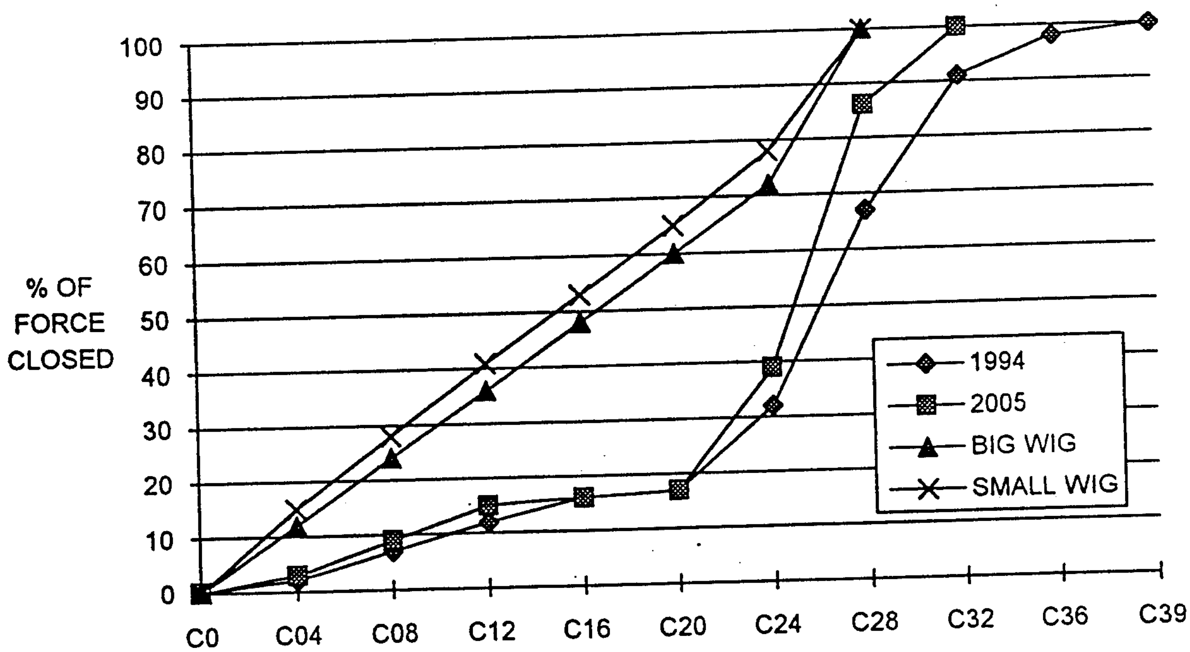

Figure 3. Force Closure, Notional Corps to SWA (LAD C+30)

Tables 10, 11, and 12 show accelerated air assault division and total force closure as the allocated number of Wingships increase due to shortened LADs. A fleet of 63 Aerocon Wingships was able to close the entire corps in less than a third of the time it takes for current assets (C+12 vice C+39).

TABLE 10
WINGSHIP REQUIREMENTS TO CLOSE
THE NOTIONAL CORPS BY
C+25

DTS MIX	AIR ASSAULT DIV CLOSES	TOTAL FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
2005 AIR ASSETS WITH (1725T) AEROCON WINGSHIP	C+02	C+24	29	311
2005 AIR ASSETS WITH (900T) NORTHROP WINGSHIP	C+02	C+25	71	708

TABLE 11
WINGSHIP REQUIREMENTS TO CLOSE
THE NOTIONAL CORPS BY
C+20

DTS MIX	AIR ASSAULT DIV CLOSES	TOTAL FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
2005 AIR ASSETS WITH (1725T) AEROCON WINGSHIP	C+02	C+19	35	311
2005 AIR ASSETS WITH (900T) NORTHROP WINGSHIP	C+02	C+20	89	708

TABLE 12
WINGSHIP REQUIREMENTS TO CLOSE
THE NOTIONAL CORPS BY
C+15

DTS MIX	AIR ASSAULT DIV CLOSES	TOTAL FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
2005 AIR ASSETS WITH (1725T) AEROCON WINGSHIP	C+02	C+12	63	311
2005 AIR ASSETS WITH (900T) NORTHROP WINGSHIP	C+02	C+17	102	708

e. Force Closure - Two Division Force. Deployment of a two division force to NEA was simulated in JFAST using an LAD (at the A/SPOD) of C+20 using all four asset mixes. Force closure profiles generated are shown in table 13. Included in this table are actual number of Wingships and total sorties required. The airborne division is the first unit to close in all cases. Closure of this division was attained by use of current air assets by C+11 and by C+08 using 2005 air assets. Closure of this division was somewhat accelerated, closing on C+06, using either of the Wingships. Similar results were shown in comparing total force closure. Current assets closed the entire force in C+34, while 2005 assets closed the total force on C+27.

The Aerocon Wingship and Northrop Wingship (replacing all RORO ships) closed the entire force on C+19, while using a relatively small portion of the total Wingships allocated. Closure profiles of the two division force are illustrated in figure 4.

TABLE 13
FORCE CLOSURE - TWO DIVISION FORCE
(MECHANIZED/AIRBORNE)
WITH LAD OF C+20

DTS MIX	AIRBORNE DIV CLOSES	TOTAL FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
CURRENT ASSETS	C+11	C+34		
YEAR 2005 ASSETS	C+08	C+27		
2005 ASSETS WITH (1725T) AEROCON WINGSHIP	C+06	C+19	13	74
2005 ASSETS WITH (900T) NORTHROP WINGSHIP	C+06	C+19	40	199

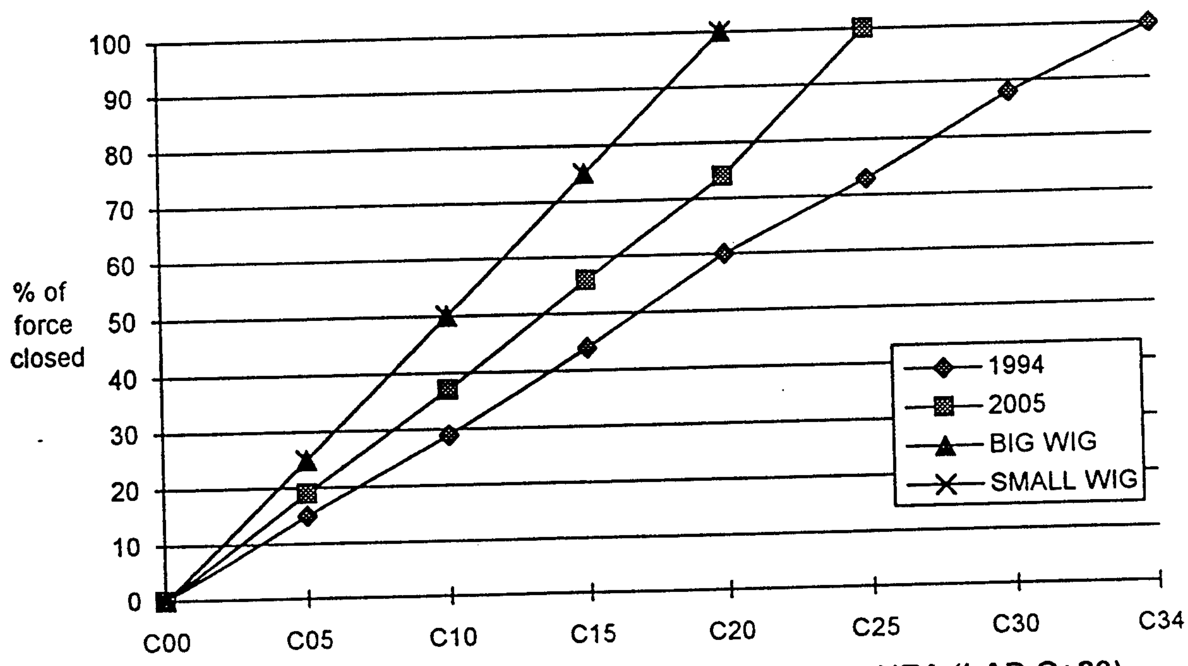

Figure 4. Force Closure, 2 Division Force to NEA (LAD C+20)

Tables 14 and 15 show accelerated airborne division and total force closure as the number of actual Wingship assets increase due to shortened LADs. Current and 2005 asset closure profiles do not change as LADs decrease since both are fully utilized with an LAD of C+20. The Northrop Wingship approaches the allocated number (120) of assets to close the force at C+10. Total Wingship sorties increase from those shown in table 13 as the Wingship also moves unit equipment that can not be delivered within the accelerated LAD by the C-17 or C-5 aircraft. A relatively low number (41) of Aerocon Wingships are required to close by C+10. Figure 5 illustrates force closure profiles with an LAD of C+10.

TABLE 14
FORCE CLOSURE - TWO DIVISION FORCE
WITH LAD OF C+15

DTS MIX	AIRBORNE DIV CLOSES	TOTAL FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
2005 ASSETS WITH (1725T) AEROCON WINGSHIP	C+04	C+15	19	95
2005 ASSETS WITH (900T) NORTHROP WINGSHIP	C+05	C+14	64	255

TABLE 15
FORCE CLOSURE - TWO DIVISION FORCE
WITH LAD OF C+10

DTS MIX	AIRBORNE DIV CLOSES	TOTAL FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
2005 ASSETS WITH (1725T) AEROCON WINGSHIP	C+02	C+08	41	122
2005 ASSETS WITH (900T) NORTHROP WINGSHIP	C+03	C+10	109	325

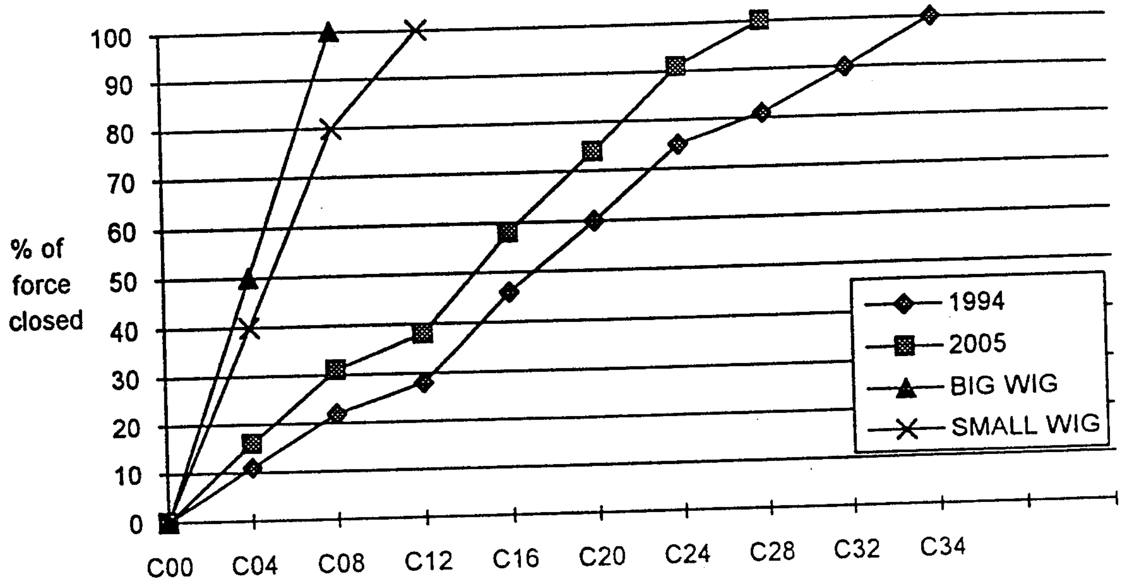

Figure 5. Force Closure, 2 Division Force to NEA (LAD C+10)

f. Force Closure - Separate Mechanized Brigade. Deployment of a separate mechanized brigade to the Caribbean was simulated in JFAST using an LAD (at the A/SPOD) of C+10 using current and 2005 air and ship asset mixes separately, in addition to using each of the two Wingships as the sole transport asset. Force closure profiles generated are shown in table 16. Included in this table are actual number of Wingships and total sorties required. Closure of this brigade was attained by use of current ship assets by C+11 and current air assets by C+15. 2005 ship assets attained closure by C+13 and 2005 air assets by C+09. Use of air assets in this scenario were constrained by APOD throughput, resulting in a rather late force closure for current air assets. Current and 2005 assets were fully utilized with the assigned LAD of C+10. Wingships were underutilized as shown by the low number of Wingships required. Force closure using only two Aerocon Wingships was C+08, and C+09 when using three Northrop Wingships. Figure 6 illustrates force closure of the Separate mechanized brigade with an LAD of C+10.

TABLE 16
FORCE CLOSURE - SEPARATE MECH BRIGADE

DTS MIX	FORCE CLOSES	AIR SORTIE REQUIREMENTS	WINGSHIPS REQUIRED
CURRENT SHIP ASSETS	C+11		
CURRENT AIR ASSETS	C+15	C141-380, C5-129	
YEAR 2005 SHIP ASSETS	C+13		
YEAR 2005 AIR ASSETS	C+09	C17-121. C5-129	
1725 TON AEROCON WINGSHIP ONLY	C+08	16	2
900 TON NORTHROP WINGSHIP ONLY	C+09	36	3

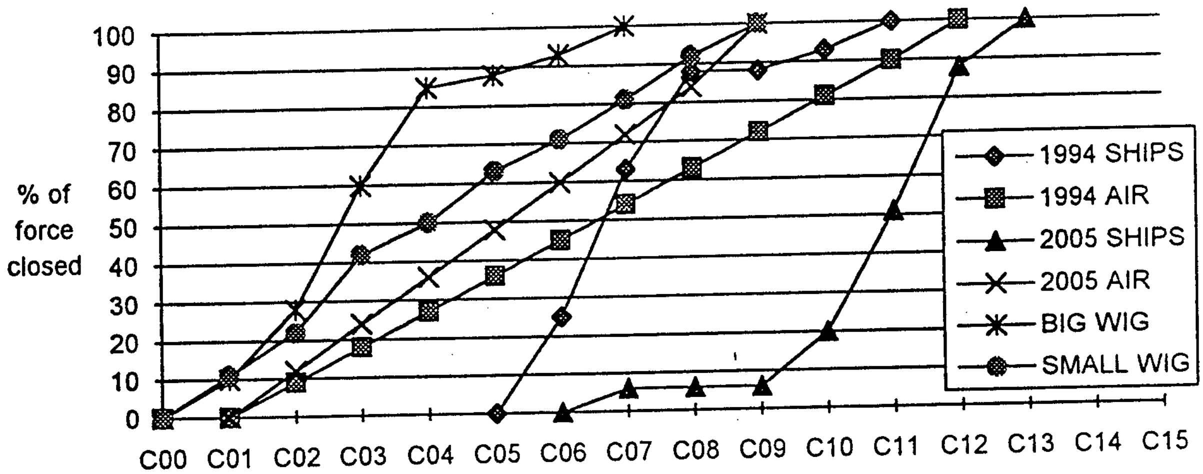

Figure 6. Force Closure, Separate Mech Brigade to Caribbean (LAD C+10)

Tables 17, 18, and 19 show accelerated force closure as the number of actual Wingship assets increase due to shortened LADs. Current and 2005 asset closure profiles do not change as LADs decrease since both are fully utilized with an LAD of C+10. As shown in table 19, this mech brigade can be closed in a very short time (C+01) using a rather low number of either Wingship design. Figures 7 and 8 illustrate force closure profiles with LADs of C+05 and C+02.

TABLE 17
FORCE CLOSURE - SEPARATE MECH BRIGADE
WITH LAD OF C+05

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+04	4	16
900 TON NORTHROP WINGSHIP ONLY	C+05	6	36

TABLE 18
FORCE CLOSURE - SEPARATE MECH BRIGADE
WITH LAD OF C+02

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+02	8	16
900 TON NORTHROP WINGSHIP ONLY	C+02	18	36

TABLE 19
FORCE CLOSURE - SEPARATE MECH BRIGADE
WITH LAD OF C+01

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+01	16	16
900 TON NORTHROP WINGSHIP ONLY	C+01	36	36

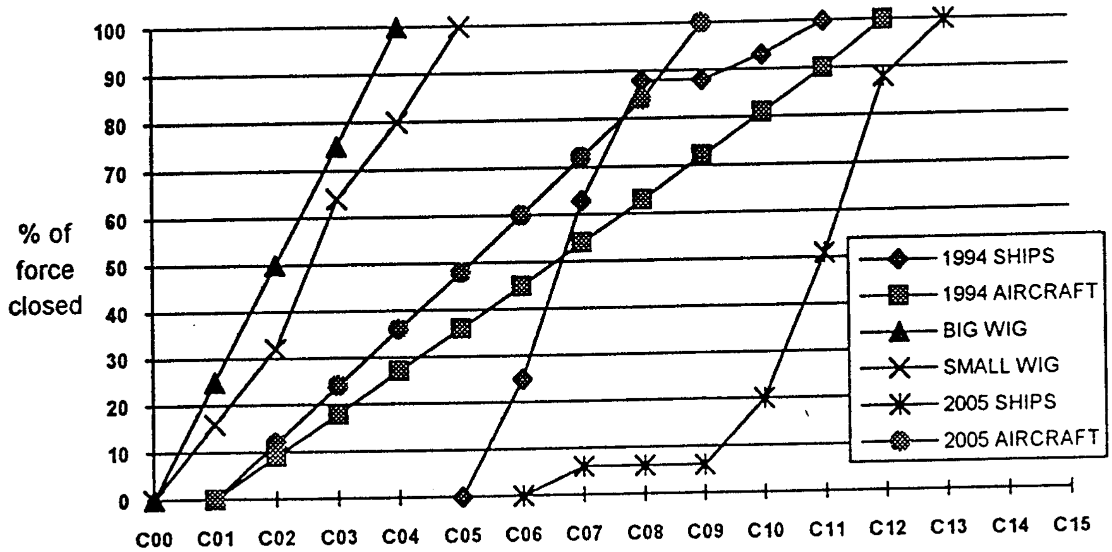

Figure 7. Force Closure, Separate Mech Brigade to Caribbean (LAD C+5)

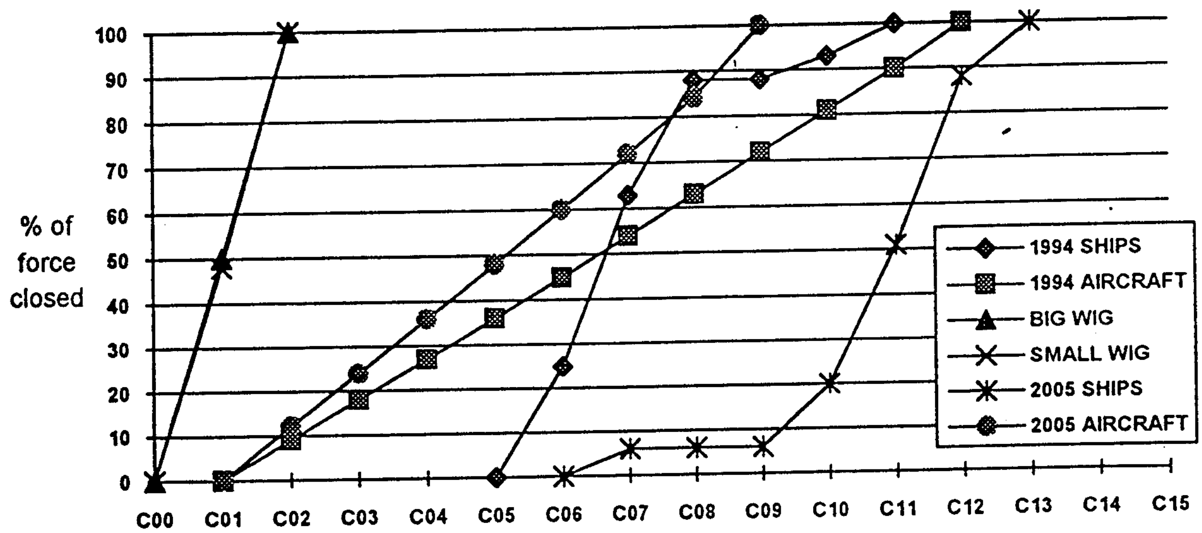

Figure 8. Force Closure, Separate Mech Brigade to Caribbean (LAD C+2)

g. Force Closure - 10K Early Entry Force. Deployment of the 10K force to SWA was simulated in JFAST using an LAD (at the A/SPOD) of C+20 using current and 2005 air and ship asset mixes separately, in addition to using each of the two Wingships as the sole transport asset. Force closure profiles generated are shown in table 20. Included in this table are actual number of Wingships and total sorties required. Closure of this force was attained by use of current sealift assets by C+23 and by C+24 using 2005 sealift assets. Force closure improved slightly with the use of current air assets only to C+20 and with 2005 air assets to C=16. Current and 2005 allocated assets were fully utilized to try and meet the LAD of C+20. Closure of this force was accelerated, closing on C+14, using either of the Wingships. Closure profiles of the 10K are illustrated in figure 9.

TABLE 20
FORCE CLOSURE - 10K EARLY ENTRY FORCE

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
CURRENT SHIP ASSETS	C+23		
YEAR 2005 SHIP ASSETS	C+24	-	
CURRENT AIR ASSETS	C+20		
YEAR 2005 AIR ASSETS	C+16	-	
1725 TON AEROCON WINGSHIP ONLY	C+14	6	31
900 TON NORTHROP WINGSHIP ONLY	C+14	17	82

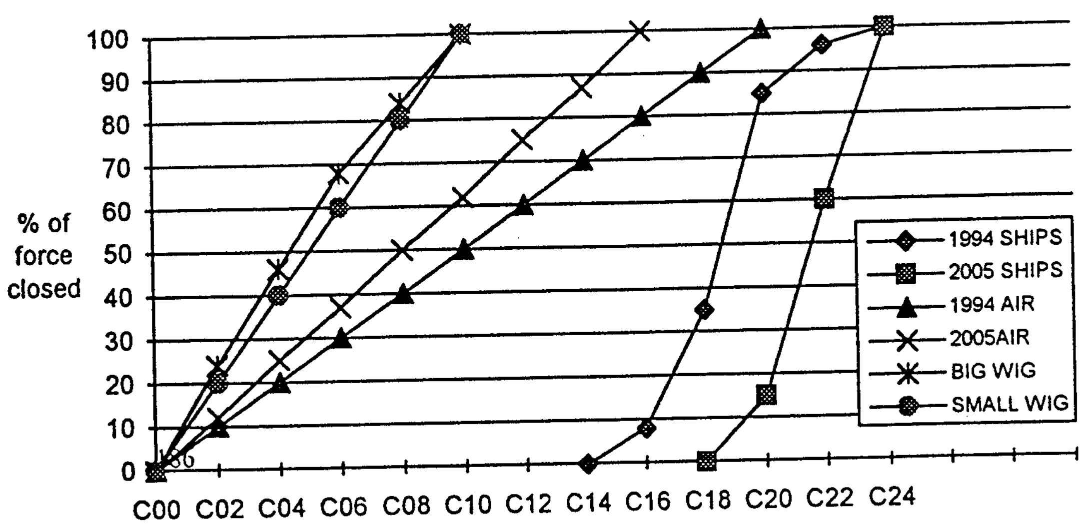

Figure 9. Force Closure, 10 K Force to SWA (LAD C+20)

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Tables 21, 22, and 23 show accelerated force closure as the number of actual Wingship assets increase due to shortened LADs. Current and 2005 asset closure profiles do not change as LADs decrease since both are fully utilized with an LAD of C+20. As shown in table 22, this 10K force can be closed in a very short time (C+02) using 31 Aerocon Wingships or 82 Northrop Wingships. Figure 10 illustrates force closure profiles with a LAD of C+05.

TABLE 21
FORCE CLOSURE - 10K EARLY ENTRY FORCE
WITH LAD OF C+10

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+08	8	31
900 TON NORTHROP WINGSHIP ONLY	C+10	21	82

TABLE 22
FORCE CLOSURE - 10K EARLY ENTRY FORCE
WITH LAD OF C+05

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+04	16	31
900 TON NORTHROP WINGSHIP ONLY	C+05	41	82

TABLE 23
FORCE CLOSURE - 10K EARLY ENTRY FORCE
WITH LAD OF C+02

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+02	31	31
900 TON NORTHROP WINGSHIP ONLY	C+02	82	82

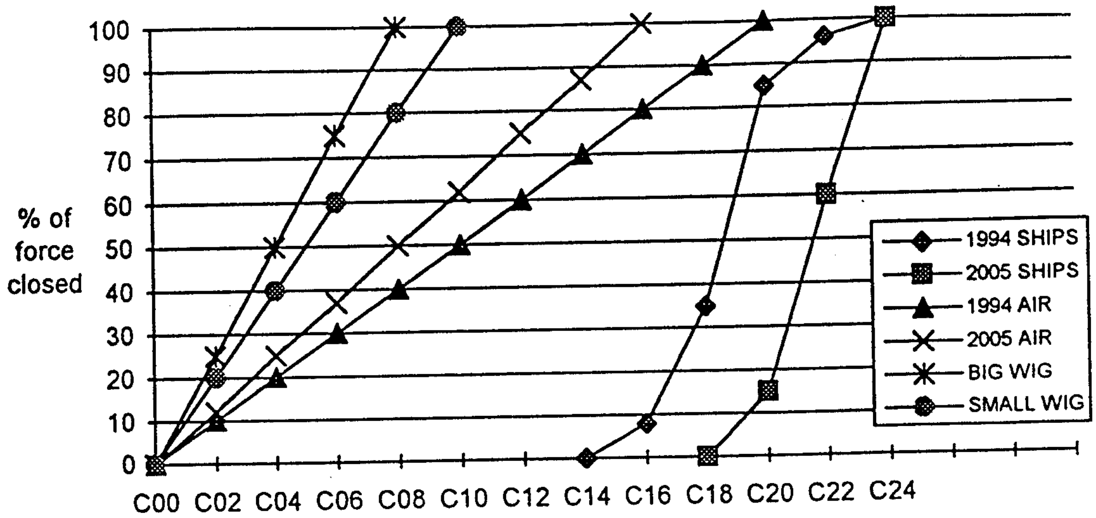

Figure 10. Force Closure, 10 K Force to SWA (LAD C+10)

i. Force Closure - 2K Early Entry Force. Deployment of the 2K force to SWA was simulated in JFAST using an LAD (at the A/SPOD) of C+10 using current and 2005 air and ship asset mixes separately in addition to using each of the two Wingships as the sole transport asset. Force closure profiles generated are shown in table 24 Included in this table are actual number of Wingships and total sorties required. Closure of this force was attained by use of current ship assets by C+18 and current air assets by C+09. 2005 ship assets attained closure by C+23 and 2005 air assets by C+06. Use of air assets in this scenario were not constrained by airfield throughput. Current and 2005 assets were fully utilized to attempt to meet the LAD of C+10. Wingships were underutilized as shown by the low number of Wingships required. Force closure using the Aerocon Wingship was C+06 and C+07 when using the Northrop Wingship. Figure 11 illustrates force closure of the 2K with an LAD of C+10.

TABLE 24
FORCE CLOSURE - 2K EARLY ENTRY FORCE

DTS MIX	FORCE CLOSES	AIR SORTIE REQUIREMENTS	WINGSHIPS REQUIRED
CURRENT SHIP ASSETS	C+18		
CURRENT AIR ASSETS	C+09	C141-467, C5-12	
YEAR 2005 SHIP ASSETS	C+23		
YEAR 2005 AIR ASSETS	C+06	C17-145, C5-12	
1725 TON AEROCON WINGSHIP ONLY	C+06	12	4
900 TON NORTHROP WINGSHIP ONLY	C+07	31	12

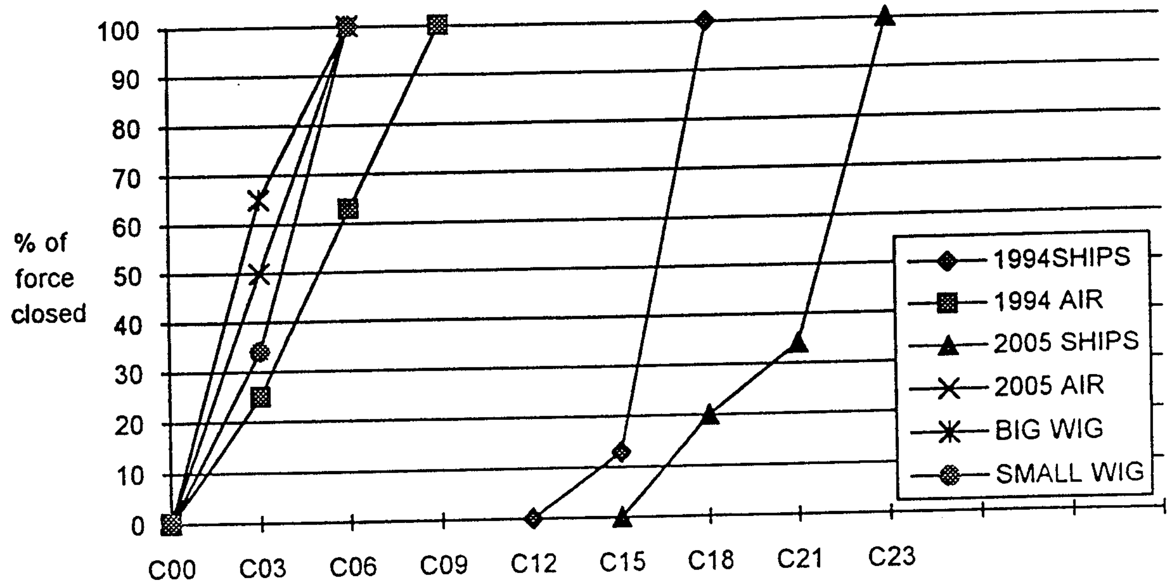

Figure 11. Force Closure, 2K Force to SWA (LAD C+20)

Tables 25 and 26 show accelerated force closure as the number of actual Wingship assets increase due to shortened LADs. Current and 2005 asset closure profiles do not change as LADs decrease since both are fully utilized with an LAD of C+10. As shown in table 26, this 2K force can be closed in a very short time (C+02) with only 12 Aerocon Wingships or 31 Northrop Wingships. Figure 12 illustrates force closure profiles with a LAD of C+02.

TABLE 25
FORCE CLOSURE - 2K EARLY ENTRY FORCE
WITH LAD OF C+05

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+04	6	12
900 TON NORTHROP WINGSHIP ONLY	C+05	16	31

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TABLE 26
FORCE CLOSURE - 2K EARLY ENTRY FORCE
WITH LAD OF C+02

DTS MIX	FORCE CLOSES	WINGSHIPS REQUIRED	WINGSHIP SORTIES
1725 TON AEROCON WINGSHIP ONLY	C+02	12	12
900 TON NORTHROP WINGSHIP ONLY	C+02	31	31

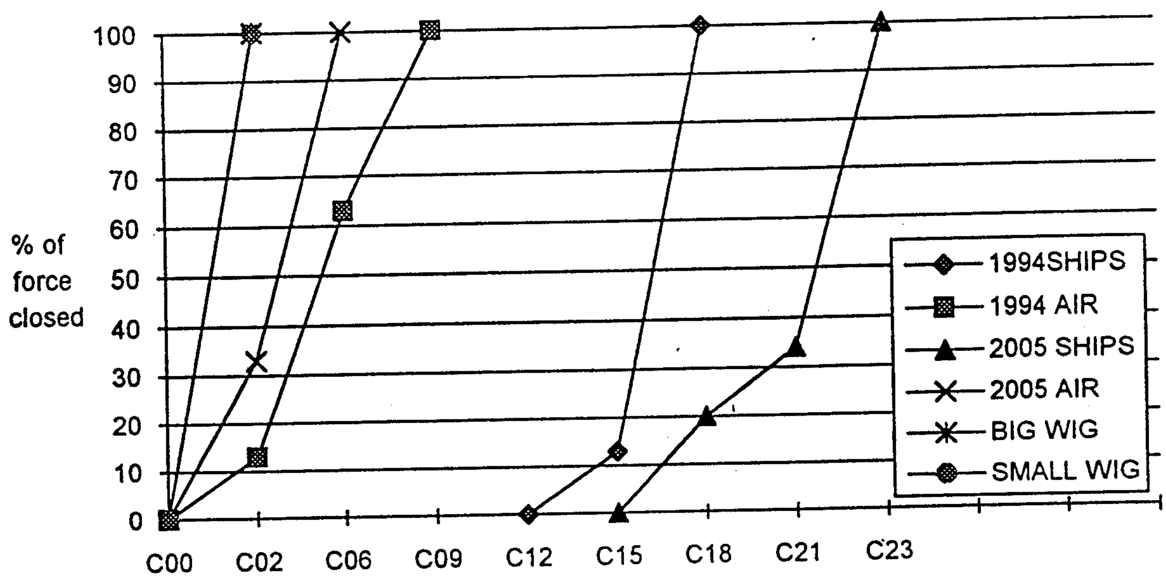

Figure 12. Force Closure, 2 K Force to SWA (LAD C+02)

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6. Summary of Analysis

a. Best Case Force Closure. Summaries of force closure showing the earliest possible closure date for each of the asset mixes to deploy each of the five forces analyzed are listed in tables 27 and 28. The closure dates are dependent upon optimal use of available/allocated resources. Allocation of existing assets was based on the actual inventory of those assets with utilization rates and estimated operational tempo factored in. Allocation of the Aerocon Wingship was set at a maximum of 65 Wingships in each case. Allocation of the Northrop Wingship was set at a maximum of 120 Wingships in each case. Tables 27 and 28 also summarize actual number of Wingships (shown in parenthesis) required to attain the closure dates listed. As these two tables illustrate, either of the two Wingship designs are capable of drastically reducing the time required to close either of the five forces. However, the number of Wingships required to attain early closure dates for the notional corps and the two division force are higher than is reasonably expected to ever be procured.

TABLE 27
BEST CASE
FORCE CLOSURE SUMMARY
WITH ASSET MIX

DTS MIX	NOTIONAL CORPS	2 DIVISION FORCE
CURRENT ASSETS	C+39	C+34
YEAR 2005 ASSETS	C+31	C+27
1725 TON AEROCON WINGSHIP ONLY	C+12 (63)	C+5 (65)
900 TON NORTHROP WINGSHIP ONLY	C+17 (102)	C+10 (109)

TABLE 28
BEST CASE
FORCE CLOSURE SUMMARY
USING ASSET TYPES SEPARATELY

DTS MIX	SEPARATE MECH BRIGADE	10K EARLY-ENTRY FORCE	2K EARLY-ENTRY FORCE
CURRENT SHIP ASSETS	C+11	C+23	C+18
CURRENT AIR ASSETS	C+15	C+20	C+09
YEAR 2005 SHIP ASSETS	C+13	C+24	C+23
YEAR 2005 AIR ASSETS	C+09	C+16	C+06
1725 TON AEROCON WINGSHIP ONLY	C+01 (16)	C+02 (31)	C+02 (12)
900 TON NORTHROP WINGSHIP ONLY	C+01 (36)	C+02 (82)	C+02 (31)

b. Most Economical Case Force Closure. Summaries of force closure requiring the fewest number of Wingships to deploy each of the five forces to meet probable, realistic LADs are listed in tables 29 and 30. The closure dates are dependent upon most economical use of available/allocated resources. Allocation of the Aerocon Wingship was set at a maximum of 65 Wingships in each case. Allocation of the Northrop Wingship was set at a maximum of 120 Wingships in each case. The actual number of Wingships required to attain the closure dates listed are shown in parenthesis. Although closure dates do not change for current or 2005 assets, their closure times are repeated for comparison purposes. As these two tables illustrate, a relatively small number of either Wingship design is necessary to close any of the forces within very realistic LADs.

TABLE 29
MOST ECONOMICAL
FORCE CLOSURE SUMMARY
WITH ASSET MIX

DTS MIX	NOTIONAL CORPS LAD C+30	2 DIVISION FORCE LAD C+20
CURRENT ASSETS	C+39	C+34
YEAR 2005 ASSETS	C+31	C+27
2005 ASSETS WITH (1725T) AEROCON WINGSHIP	C+30 (23)	C+19 (13)
2005 ASSETS WITH (900T) NORTHROP WINGSHIP	C+29 (59)	C+19 (40)

TABLE 30
MOST ECONOMICAL
FORCE CLOSURE SUMMARY
USING ASSETS TYPES SEPARATELY

DTS MIX	SEPARATE MECH BRIGADE LAD C+10	10K EARLY ENTRY FORCE LAD C+20	2K EARLY ENTRY FORCE LAD C+10
CURRENT SHIP ASSETS	C+11	C+23	C+18
CURRENT AIR ASSETS	C+15	C+20	C+09
YEAR 2005 SHIP ASSETS	C+13	C+24	C+23
YEAR 2005 AIR ASSETS	C+09	C+16	C+06
1725 TON AEROCON WINGSHIP ONLY	C+08 (2)	C+19 (4)	C+08 (3)
900 TON NORTHROP WINGSHIP ONLY	C+09 (3)	C+20 (11)	C+10 (8)

IV. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Air Sortie/Sealift Requirements Comparison

A comparison of air sortie requirements to deploy the five forces (table 4) illustrates the large advantage the Wingship possesses in number of sorties required to transport various Army forces. At the same time, the Wingship concedes very little in cruise speed capability to existing strategic lift aircraft. The Aerocon Wingship, and to a lesser degree, the Northrop design, also compare favorably to the DTS sealift transports. A comparison of sealift requirements (table 8) shows it takes only 9 Aerocon Wingships to transport an equal amount of unit equipment as 1 large medium speed RORO (LMSR), while the Wingship has a cruise speed nearly 17 times greater than the LMSR. This translates to one Wingship being capable of transporting nearly twice as much unit equipment, over time, as one LMSR.

2. Force Closure Profile Comparison

A comparison of force closure times, summarized in tables 27 through 30, clearly illustrates the enormous capability of the Wingship. Given adequate numbers of Wingships, a small Army Corps can be closed to Southwest Asia in less than two weeks. This possibility could revolutionize Army doctrine and Department of Defense policy. Even provided with smaller numbers of Wingships, contingency forces that are heavy and lethal could be capable of responding to any crises anywhere in days. Although the existing DTS airfleet, including the C-17, is very capable of deploying very small, light forces rapidly, it lacks the capability to deploy a credible-sized force rapidly enough to deter the many emerging, sizable enemy threats. The Wingship seems very capable of filling this role.

B. RECOMMENDATIONS

1. Based on the enormous potential value the Wingship can add to the capability of the DTS, it is highly recommended that the Wingship project proceed to the next phase and that further, more detailed analysis be conducted on this very capable transport design. The following refinement is recommended for inclusion to the follow-on Wingship designs to improve capability:

2. Reduce the troop capacity of the Aerocon design from 2,000 to 500 and convert the saved space into additional cargo deck space. Analysis has shown that the number of Wingships required to transport any given force have an average troop load of less than 500.

APPENDIX A

FORCE DATA SUMMARY

NOTIONAL CONTINGENCY CORPS

UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON
67000L100	AIR ASSAULT DIVISION	1	15850	5820	969756.5	33648.9
87000L700	AR DIV,6-M1,4-BFVS,1-AHB	1	17331	8156	1493511.8	107544.9
87000L800	MX DIV,5-M1,5-BFVS,1-AHB	1	17576	8242	1501298.0	[illegible]
17440L400	ARMD CAV REGT	1	4666	2195	444806.9	[illegible]
06365L400	FA BN 155 SP HVY DIV	1	701	197	40565.6	[illegible]
06403L000	HHB, CORPS ARTILLERY	1	204	92	12837.5	[illegible]
06402L200	HHB, FA BDE WITH TACFIRE	4	132	67	10005.0	[illegible]
06465L000	FA BATTALION MLRS	9	450	256	46179.0	[illegible]
06435L000	FA BN, 155MM T, ABN	3	589	285	49054.5	[illegible]
06413L000	CORPS TGT ACQ DETACHMENT	1	38	23	3998.4	[illegible]
52401L100	HHC CORPS	1	1326	132	15793.2	[illegible]
63422L000	HHC, SUPPORT GROUP (CORPS)	1	220	74	7543.8	[illegible]
63426L000	HHD, CORPS SUPPORT BN	1	228	68	6854.9	[illegible]
09483L000	ORD CO, AMMO (MOADS) DS	2	228	161	[illegible]	[illegible]
10468L000	WATER SUPPLY COMPANY	1	148	81	16174.1	[illegible]
10427L000	QM PETROLEUM SUPPLY CO	1	197	229	45118.0	[illegible]
52413L000	CORPS RAOC	1	98	18	2299.7	[illegible]
55716L000	HHD, TRANS MOTOR TRANS BN	1	192	28	3029.9	87.0
55540LE00	TRAILER TRANSFER POINT OP	1	66	21	3715.5	[illegible]
55729L000	TRANS HEAVY TRUCK COMPANY	1	622	178	56883.4	[illegible]
55728L200	T MDM TRK CO 5000 GAL TANK	1	694	274	56745.5	[illegible]
55719L200	TRANS LIGHT-MDM TRUCK CO	2	432	268	51209.4	[illegible]
43436L000	HHD ORD(MNT)BN DS/GS	2	48	18	[illegible]	[illegible]
01947L100	AVN MAINT CO,III CORPS-AC	2	270	187	36474.3	1426.7
43209L000	MAINT CO NON-DIVISIONAL DS	2	195	173	31712.6	[illegible]
43537LD10	SIGINT/EW EQUIP REP TM	1	7	7	1300.3	47.4
43537LE10	COMSEC EQUIP REPAIR TEAM	1	20	13	2498.9	[illegible]
43537LB00	AUTOM TEST EQUIP TEAM	1	7	6	1535.1	54.0
42419L000	QM REP PARTS SUPPLY CO	1	182	148	30572.8	1289.8
42446L000	HHD, SUPPLY AND SERVICE BN	1	61	16	1684.8	41.3
42447L000	QM SUPPLY CO	1	135	117	21713.5	1048.1
42418L000	QM SUPPLY CO, GS	1	137	47	9267.7	441.0
42518LA00	QM BAKERY TEAM/AOE	1	19	16	2510.7	124.0
42414L000	QM FLD SVC CO DS/AOE	1	106	68	10751.7	483.4
08432L000	HHD, MEDICAL GROUP	1	62	16	2034.3	59.4
08705L000	COMBAT SUPPORT HOSPITAL	1	604	78	27734.1	1399.5
08446L000	HHD, MED EVAC BN	1	45	24	[illegible]	[illegible]
08447L100	MED CO, AIR AMBL (UH-1V)	1	130	74	[illegible]	[illegible]
08407L100	MEDICAL DETACHMENT (SURG)	1	9	1	113.3	[illegible]
08498L000	MED DET, PM (SANITATION)	1	11	6	609.9	[illegible]
08499L000	MED DET, PM (ENTOMOLOGY)	1	11	8	949.8	38.1
08909L000	MED LOG SUPPORT DET	1	39	20	2836.3	[illegible]
08417L000	MED DET, VET SVC	1	48	27	2782.5	59.6
08455L000	MED BN, AREA SUPPORT	1	338	233	30745.5	1380.4
08567LA00	MED DET, CMBT STRESS CNTRL	1	24	13	1671.4	72.8
08527LA00	MED TM, HEAD & NECK SURG	1	7		0.8	0.0
08479L000	MED DET, DENTAL SVCS	1	28	24	[illegible]	[illegible]

APPENDIX A

FORCE DATA SUMMARY

NOTIONAL CONTINGENCY CORPS

UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON
03476L100	HHD CHEMICAL BATTALION	1	45	21	2587.9	[illegible]
03437L000	SMOKE GENERATOR CO (MECH)	1	107	47	7404.6	439.5
03417L000	CHEM CO (DECON)(CORP/TA)	1	134	110	18049.7	[illegible]
05415L000	ENGR COMBAT BN, HEAVY	1	663	499	92534.7	[illegible]
05423L000	ENGR CO, CSE (ENG BDE)	1	178	147	30503.3	[illegible]
55604L000	TRANS MOV CON CTR, COSCOM	1	176	21	1724.8	[illegible]
55580LA00	MOVEMENT CONTROL	1	12	2	258.7	[illegible]
55580LD00	MOVEMENT CONTROL (REGION)	1	44	5	613.1	16.4
55580LC00	MOVEMENT CONTROL	4	28	4	409.8	[illegible]
55580LB00	MOVEMENT CONTROL	1	20	2	258.7	[illegible]
55560LA00	CARGO DOCUMENTATION	2	32	2	[illegible]	[illegible]
63431L000	HHC, CORPS SPT CMD	1	1384	104	[illegible]	[illegible]
09527LB00	EOD DETACHMENT	1	23	14	[illegible]	[illegible]
63433L000	MMC, CORPS SPT CMD	1	1488	119	[illegible]	[illegible]
FORCE TOTAL			75328	[illegible]	[illegible]	[illegible]

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APPENDIX B

FORCE DATA SUMMARY

MECHANIZED AND AIRBORNE DIVISIONS

AIRBORNE DIVISION

FRC NR	UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON
1	57004L000	HHC AIRBORNE DIVISION	1	259	76	[illegible]	[illegible]
2	19313L000	MP COMPANY AIRBORNE DIV	1	102	56	5895.5	162.8
3	11065L200	DIV SIG BN (MSE)LID	1	475	422	46016.8	[illegible]
4	44135L000	ADA BN, SHORAD (ABN DIV)	1	438	335	28648.9	[illegible]
5	05025L000	ENGR BN, ABN DIV	1	429	173	[illegible]	[illegible]
6	03057L000	CHEM CO (SMK/DECON) ABN/AA	1	124	98	[illegible]	590.7
7	34265L000	MI BN (CEUI) ABN DIVISION	1	[illegible]	161	[illegible]	[illegible]
8	57042L000	HHC AIRBORNE BRIGADE	3	75	32	4175.5	[illegible]
9	07035L000	INF BN (ABN)	9	677	100	13233.4	457.7
10	06202L000	HHB DIVARTY (ABN)	1	113	62	7407.2	280.7
11	06205L000	FA BN, 105MM T (ABN) AOE	3	446	170	21037.5	838.8
12	01042L200	HHC, DIV AVU BDE (ABN)	1	139	109	17634.6	765.9
13	01045L000	ASSAULT HEL BN (UH-60)	1	279	144	[illegible]	[illegible]
14	01055L200	ATTACK HEL BN (AH-64)	1	234	120	[illegible]	[illegible]
15	01065L000	AIR RECON SQUADRON	1	343	169	[illegible]	[illegible]
16	12113L000	DIVISION & ARMY BAND (DS)	1	41	3	[illegible]	[illegible]
17	01973L200	AVN MAINT CO, ABN (AH-64)	1	229	144	[illegible]	[illegible]
18	63252L000	HHC/MMC,SPT CMD,ABN DIV	1	203	93	10603.4	[illegible]
19	63255L000	FWD SPT BN, ABN	3	236	169	25337.0	1011.8
20	63265L000	MAIN SPT BN, ABN DIV	1	936	416	146543.7	4188.4
DIVISION TOTAL				13149	4594	733749.8	24143.6

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APPENDIX B

FORCE DATA SUMMARY

MECHANIZED AND AIRBORNE DIVISIONS

MECHANIZED DIVISION

SEQ NR	UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON
1	87004L200	HHC, INF DIV (MECH)	1	272	117	15436.1	[illegible]
2	19333L000	MP CO-HVY DIV	1	153	72	[illegible]	[illegible]
3	11065L400	6 NODE DIV SIG BN (MSE)	1	635	597	[illegible]	[illegible]
4	44165L000	ADA BN, HEAVY DIV	1	640	329	42400.3	[illegible]
5	05332L000	HHD, ENGINEER BRIGADE	1	55	20	2461.9	[illegible]
6	05335L000	ENGR BN, HVY DIV	3	433	220	46769.9	[illegible]
7	34285L000	M1 BN, HVY DIV	1	465	[illegible]	[illegible]	[illegible]
8	03157L200	CHEMICAL CO, HVY DIV	1	171	113	[illegible]	[illegible]
9	87042L100	HHC, HVY DIV BDE (ARMOR)	1	81	40	5008.9	[illegible]
10	87042L200	HHC INF DIV (MECH) BDE	2	84	41	[illegible]	[illegible]
11	1 n75L000	TANK BATTALION (HVY DIV)	5	610	241	52508.9	[illegible]
12	07245L000	INF BN (MECH)	5	818	314	57375.3	[illegible]
13	06302L000	HHB DIV ARTY HVY DIV	1	187	84	[illegible]	[illegible]
14	06303L000	TGT ACQ BTRY HVY DIV	1	77	31	[illegible]	[illegible]
15	06365L400	FA BN 155 SP HVY OIV	1	708	219	[illegible]	[illegible]
16	06365L500	FA BN 155 SP HVY DIV	1	733	219	45461.8	[illegible]
17	06365L600	FA BN 155 SP HVY DIV	1	754	225	[illegible]	[illegible]
18	06398L000	FA BTRY MLRS	1	127	67	[illegible]	[illegible]
19	01302L000	HHC, DIV AVN BDE (HVY)	1	80	59	[illegible]	[illegible]
20	01303L200	ASSAULT HEL CO (UH-60)	1	131	91	25718.0	839.4
21	01304L000	COMMAND AVIATION COMPANY	1	149	91	17427.0	[illegible]
22	01385L200	ATTACK HEL BN (AH-64)	1	264	178	34552.0	1076.1
23	17385L200	DIV SQDN, CBAA AHIS HV DIV	1	550	227	[illegible]	[illegible]
24	01933L400	AVN MAINT CO,AH-64,HV DIV	1	222	136	22457.8	[illegible]
25	63002LOOO	HHC/MMC, SPT CMD, HVY DIV	1	221	90	10854.1	[illegible]
26	63005L100	FWD SPT BN (2X1) HVY DIV	1	461	292	50405.2	2652.7
27	63005L200	FWD SPT BN (2X2) HVY DIV	1	490	304	52670.9	[illegible]
28	63005L300	FWD SPT BN (1X2) HVY DIV	1	453	295	50897.9	[illegible]
29	12113L000	DIVISION & ARMY BAND (DS)	1	41	3	662.9	25.1
30	63135L000	MAIN SUPPORT BN, HVY DIV	1	1039	858	[illegible]	[illegible]
		DIVISION TOTAL		17766	8505	1543868.4	[illegible]
		FORCE TOTAL		30915	13099	[illegible]	[illegible]

APPENDIX C

FORCE DATA SUMMARY

SEPARATE MECHANIZED BRIGADE

SEQ NR	UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON	UNIT MTON
1	87102L200	HHC HVY SEP BDE (MECH)	1	337	168	22102.5	1010.6	3652.3
2	05143L000	ENGR CO, HVY SEP BDE	1	202	112	23577.4	[illegible]	[illegible]
3	17387L200	CAV TRP, CAV SQDN	1	131	37	7724.8	657.5	[illegible]
4	17587LB00	SEP CAV TROOP AUG TEAM	1	26	22	3644.4	177.7	610.3
5	34144L000	MI CO (CEWI) HVY SEP BDE	1	106	47	7059.0	[illegible]	[illegible]
6	17375L000	TANK BATTALION (HVY DIV)	1	610	241	52508.9	[illegible]	10911.3
7	07245L000	INF BN (MECH)	2	818	314	[illegible]	[illegible]	[illegible]
8	06375L200	FA BN,155MM SP, HSB (AOE)	1	602	205	38673.8	[illegible]	[illegible]
9	63085L200	SPT BN, HVY SEP BDE (1X2)	1	695	447	81662.4	4126.9	[illegible]
FORCE TOTAL				4345	1907	[illegible]	[illegible]	[illegible]

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APPENDIX D

FORCE DATA SUMMARY

NOTIONAL 10K FORCE

UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON
07035L000	INF BN (ABN)	3	677	105	11504.6	428.5
57042L000	HHC AIRBORNE BRIGADE	1	74	32	4027.2	127.4
57004L000	HHC AIRBORNE DIVISION	1	258	69	8248.6	288.5
06205L000	FA BN, 105MM T (ABN) AOE	1	441	162	19728.5	[illegible]
44437L000	ADA BTRY, AVENGER	1	82	43	5260.9	199.7
05027L000	ENGR CO, ENGR BN, ABN DIV	1	94	30	3481.3	111.8
05443L100	ENGR CO, LIGHT EQUIP, ABN	1	176	125	24610.5	[illegible]
34265L000	MI BN (CEWI) ABN DIVISION	1	408	137	[illegible]	[illegible]
11065L000	DIV SIG BN (MSE)	1	462	351	42586.9	[illegible]
19313L000	MP COMPANY AIRBORNE DIV(-)	1	96	53	5566.4	146.7
03057L000	CHEM CO (SMK/DECON) ABN/AA	1	125	119	15101.3	[illegible]
01267L300	AIR RECON TROOP (OH-58D)	3	27	14	[illegible]	[illegible]
01055L300	ATTACK HEL BN (OH-58D)	1	233	[illegible]	[illegible]	[illegible]
01303L200	ASSAULT HEL CO (UH-60)	2	131	94	[illegible]	[illegible]
17275L000	LIGHT ARMOR BATTALION	1	533	[illegible]	[illegible]	[illegible]
111111111	LIGHT CAVALRY TROOP	1	119	42	5944.9	[illegible]
06398L000	FA BTRY MLRS	1	142	79	15621.7	[illegible]
44637L000	ADA BTRY, PATRIOT	1	86	42	10210.9	589.4
01269L300	AVIATION UNIT MAINT TROOP	1	105	36	4640.6	[illegible]
08058L100	MEDICAL CO (FSB) HVY DIV	1	91	41	5981.0	[illegible]
63266L666	MSB(-) FOR 10K FORCE	1	178	64	13198.4	575.1
63422L000	CSS AMMO	1	4	18	5554.2	275.7
63433L000	MAT MGT CENTER OFFICE	1	7	1	118.9	3.1
55580LF00	MOVEMENT CON (AIR TERM)	1	34	3	381.8	[illegible]
55817L200	TRANS CARGO TRANSFER CO	1	232	106	30210.0	[illegible]
01427L300	ATS COMPANY (CORPS)	1	33	29	4368.2	147.0
222222222	HHC, CORPS FOR 10K FORCE	1	312	36	4486.2	136.4
01385L200	ATTACK HEL BN (AH-64)	1	293	184	36267.5	1106.9
01217L000	COMMAND AVIATION CO (UH-1)	1	49	19	7151.6	53.0
01266L000	HHT, AIR RECON SQUADRON	1	113	86	[illegible]	[illegible]
17207L000	CAV TRP (GROUND)	1	66	24	2787.7	88.6
333333333	IMMEDIATE READY COMPANY	1	86	14	3593.4	487.2
44497L000	ADA BTRY, HAWK (CORPS)	1	89	94	18012.7	1029.3
06413L000	CORPS TGT ACQ DETACHMENT	1	38	17	3129.7	181.5
05447L100	ENGR CO, ENGR CBT BN, ABN	1	126	68	12474.0	643.3
05427L000	ENGR CBT CO, CORP (WHL)	1	119	74	[illegible]	784.5
01913A300	RAS AMC	1	213	117	20498.9	724.9
01946A000	AMB HHD	1	59	12	1344.6	36.5
01947A300	GS AMC	1	177	105	19670.5	[illegible]
01948A200	ATK AMC	1	175	101	[illegible]	[illegible]
01953A000	AMC	1	271	117	[illegible]	[illegible]
01973L100	AVN MAINT CO, ABN (AH-1)	1	210	[illegible]	[illegible]	[illegible]
01207L000	ASSAULT HEL CO/TRP (UH-60)	1	49	23	15678.5	336.1
43209L000	MAINT CO NON-DIVISIONAL DS	1	165	120	[illegible]	[illegible]
06435L000	FA BN, 155MM T, ABN	1	598	207	32928.3	1971.0
08577LA00	HOSP UNIT, SURG FWD (HUSF)	1	38	[illegible]	767.0	48.9
08909L000	MED LOG SUPPORT DET	1	26	17	[illegible]	[illegible]

APPENDIX D

FORCE DATA SUMMARY

NOTIONAL 10K FORCE

UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON
08447L200	MED CO, AIR AMBL (UH-60A)	1	45	57	21440.4	[illegible]
08498L000	MED DET, PM (SANITATION)	1	11	6	635.4	[illegible]
08457L000	MEDICAL COMPANY (AREA SPT)	1	70	37	4312.7	[illegible]
08449L000	MEDICAL AMBULANCE COMPANY	1	22	58	7383.0	[illegible]
08446L000	HHD, MED EVAC BN	1	46	18	2001.6	[illegible]
41718L000	CA DET (DIRECT SUPPORT)	1	45	13	1479.3	36.[illegible]
08419L000	MED DET, VET SVC (SMALL)	1	6	4	416.5	9.[illegible]
33708L000	PSYOP TACTICAL COMPANY	1	78	20	2765.8	[illegible]
34235L100	MI BN (TE), AIRBORNE CORPS	1	480	219	26968.7	[illegible]
19477L000	MP CO COMBAT SUPPORT	1	176	70	7625.8	[illegible]
03457L000	CHEMICAL CO (SMK/DECON)	1	145	124	17426.[illegible]	[illegible]
08813L000	3 PATIENT ADMIN SEC	1	200	13	6360.6	[illegible]
55555L500	CHAPLAIN UNIT FOR 10K FORC	1	30	15	1583.[illegible]	[illegible]
66666L666	CMMS FOR 10K FORCE	1	87	30	[illegible]	[illegible]
12427L000	PERS DET (PERS SVCS CMD)	1	48	[illegible]	[illegible]	[illegible]
14423L000	FINANCE DETACHMENT	1	19	6	617.[illegible]	14.[illegible]
08567LA00	MED DET, CMBT STRESS CNTRL	1	23	21	[illegible]	[illegible]
45423L000	PRESS CAMP HQ	1	28	10	1310.4	[illegible]
FORCE TOTAL			11218	4756	79881.[illegible]	[illegible]

APPENDIX E

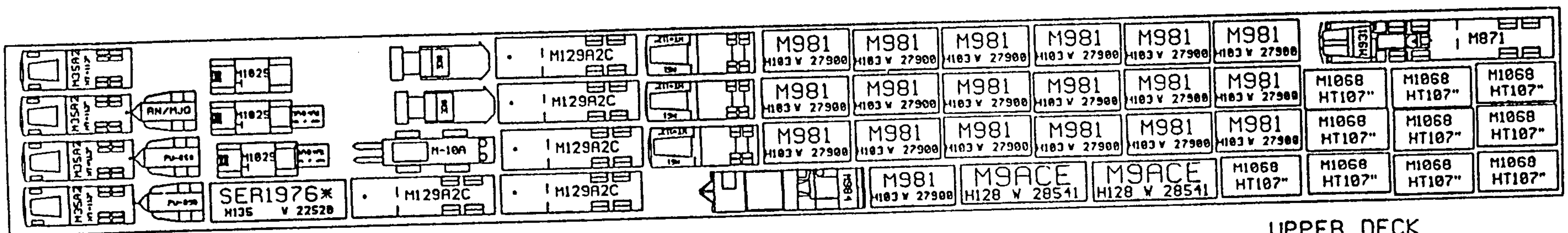
FORCE DATA SUMMARY

NOTIONAL 2K FORCE

UNIT SRC	UNIT DESCRIPTION	UNIT MULT	PERSONNEL STRENGTH	VEHICLE QUANTITY	UNIT SQFT	UNIT STON
01046L000	HHC, ASSAULT HEL BN(UH-60)	1	56	19	2427.1	85.3
01047L000	ASSAULT HEL CO (UH-60)	2	49	23	15643.0	[illegible]
01048L000	2 OBSN HEL PLT (C3)	1	24	8	[illegible]	[illegible]
01049L000	AIRCRAFT MAINT PLT	1	40	12	2090.3	[illegible]
01267L300	AIR RECON TROOP (OH-58D)	1	27	14	3187.8	[illegible]
01376L200	HHC, ATTACK HEL BN (AH-64)	1	149	52	9648.4	[illegible]
01377L200	ATTACK HEL CO (AH-64)	3	32	12	3508.1	53.0
01869L000	AIRCRAFT MAINT PLT	1	32	7	1216.1	[illegible]
03057L000	SMK/DECON PLT	1	29	34	[illegible]	[illegible]
05027L000	ENGR CO, ENGR BN, ABN DIV	1	94	30	3451.7	[illegible]
06206L000	HHB FA BN 105MM T (ABN)	1	225	75	[illegible]	[illegible]
06207L000	FA BTRY 105MM T (ABN)	3	72	29	[illegible]	[illegible]
06413L000	CORPS TGT ACQ DETACHMENT	1	38	17	[illegible]	[illegible]
06466L000	HHS BTRY MLRS BN	1	79	[illegible]	[illegible]	[illegible]
06467L000	FA BTRY MLRS	1	103	[illegible]	[illegible]	[illegible]
07036L000	HHC INF BN (ABN)	3	[illegible]	[illegible]	[illegible]	[illegible]
07037L000	RIFLE CO (ABN)	9	132		[illegible]	[illegible]
07038L000	ANTIARMOR COMPANY	3	88	32	[illegible]	[illegible]
08057L000	TRMT PLATOON	1	52	26	[illegible]	[illegible]
08067L000	FWD SPT MEDICAL CO (ABN)	1	62	37	[illegible]	[illegible]
10337L000	SUPPLY-MAINT PLT	1	84	50	61806.6	[illegible]
11066L200	HHC,SIG BN,(MSE)LID/ABN/AA	1	119	61	6829.1	[illegible]
11067L200	AREA SIG CO(MSE)LID/ABN/AA	1	140	142	[illegible]	[illegible]
11068L200	SIG SPT CO(MSE)LID/ABN/AA	1	67	44	5206.2	[illegible]
11568LA00	FORCED ENTRY SIG DET AA/AB	1	24	14	[illegible]	[illegible]
17207L000	SCOUT PLATOON	1	15	5	[illegible]	[illegible]
17276L000	HQ AND HQ COMPANY	1	281	136	[illegible]	[illegible]
17277L000	LT ARMD CO	3	63	19	3356.1	[illegible]
19313L000	MP PLATOON	1	42	22	2164.8	[illegible]
34627L000	MI CO, INTG/EXPL(EPW)	1	60	8	984.8	[illegible]
34628L000	MI CO, INTG/EXPL(GS)	1	136	10	[illegible]	[illegible]
42056L000	SUPPLY PLATOON	2	33	22	3946.1	[illegible]
43056L000	MAINT PLATOON	1	53	43	[illegible]	[illegible]
43058L000	MAINT PLATOON	2	95	25	[illegible]	[illegible]
44137L000	ADA BTRY VUL/MPDS (ABN)	1	111	68	7041.0	194.1
44637L000	ADA BTRY, PATRIOT	1	86	42	10183.6	585.6
55158L000	LT MED TRK PLT	1	29	31	[illegible]	[illegible]
57004L000	HHC AIRBORNE DIVISION	1	258	26	3355.0	120.6
57042L000	HHC AIRBORNE BRIGADE	1	74	32	[illegible]	[illegible]
FORCE TOTAL			5472	1790	[illegible]	[illegible]

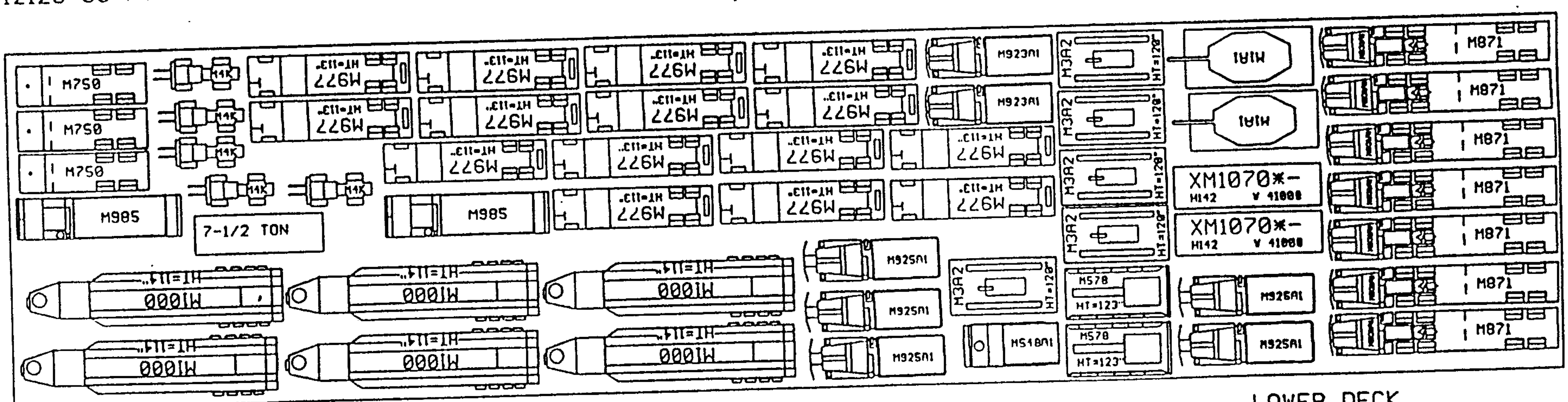
APPENDIX F
CODES STOW PLAN
SEPARATE MECHANIZED BRIGADE
ON
1725-TON PAYLOAD WINGSHIP

WINGSHIP (SHIP 1)
1725 TON PAYLOAD
SEPARATE MECHANIZED BRIGADE



UPPER DECK

12129 SQ FT 311'X 39' 13'6" HEIGHT

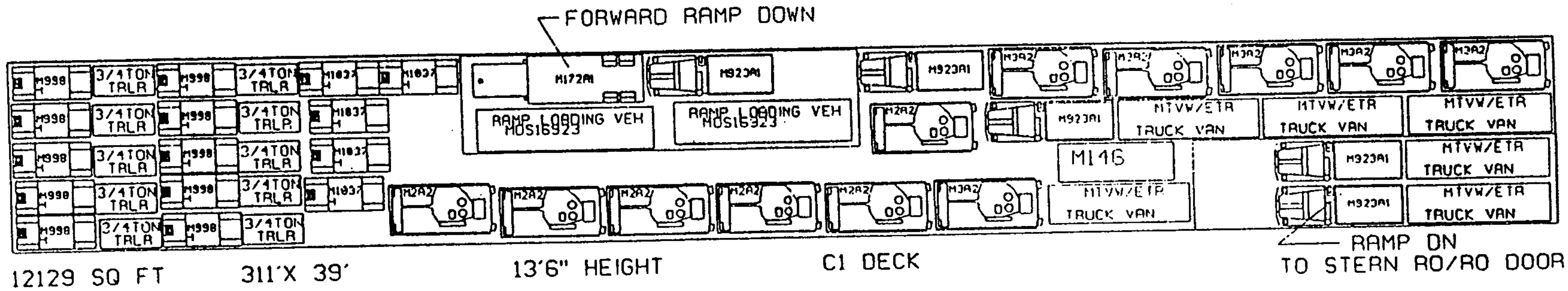


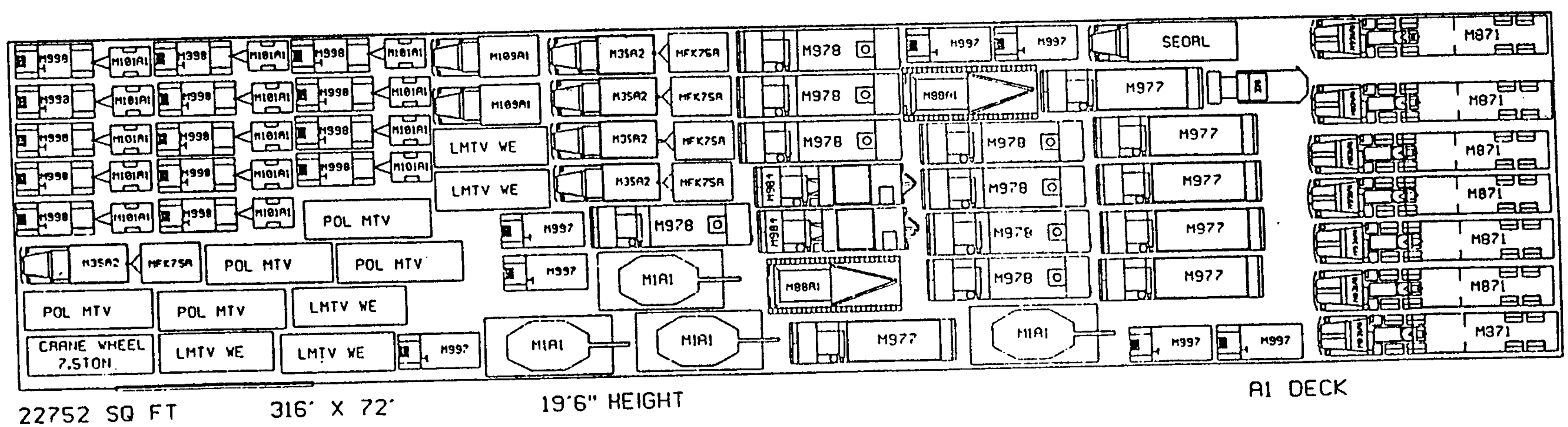
LOWER DECK

22752 SQ FT 316' X 72' 19'6" HEIGHT

SHIP 2

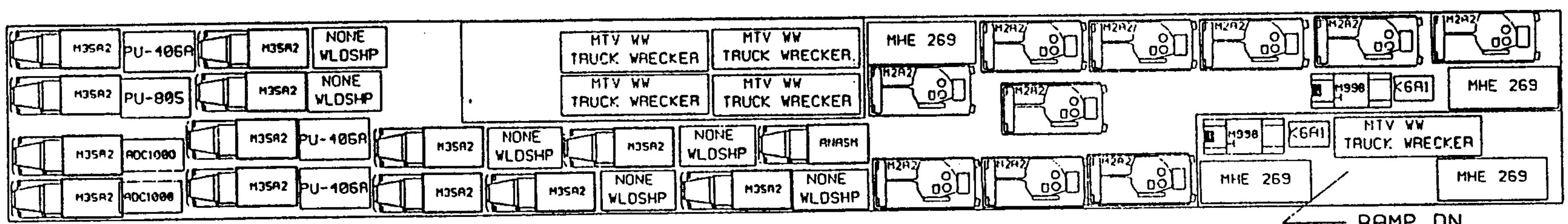
WINGSHIP
1725 TON PAYLOAD





LOAD 3
WINGSHIP
1725 TON PAYLOAD

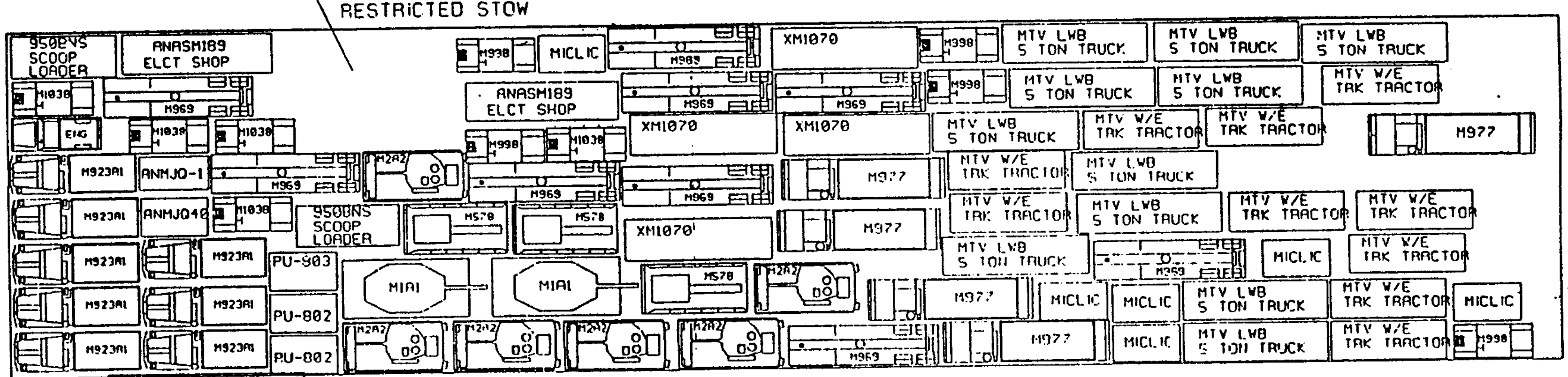
FORWARD RAMP DOWN



12129 SQ FT 311' X 39' 13'6" HEIGHT C1 DECK

RAMP ON TO STERN RO/RO DOOR

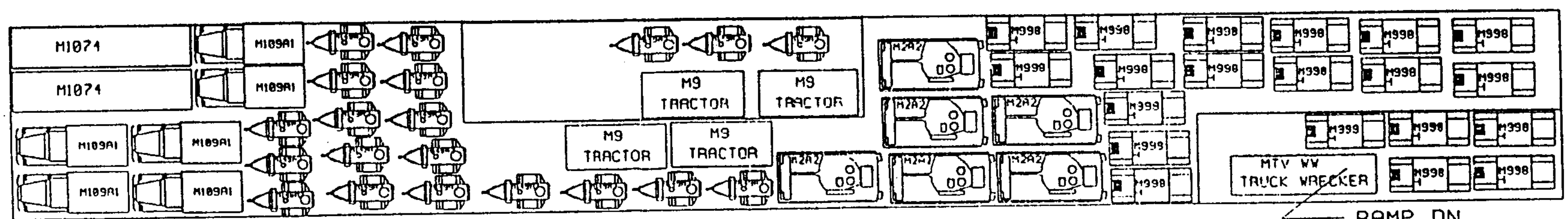
RAMP OVER HEAD RESTRICTED STOW



22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK

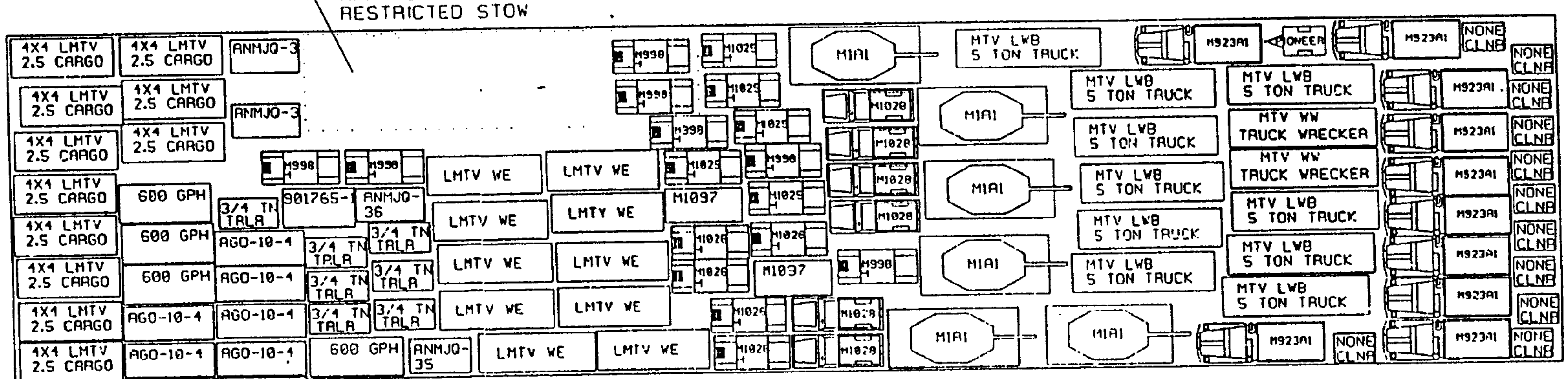
LOAD 4
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN



12129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK

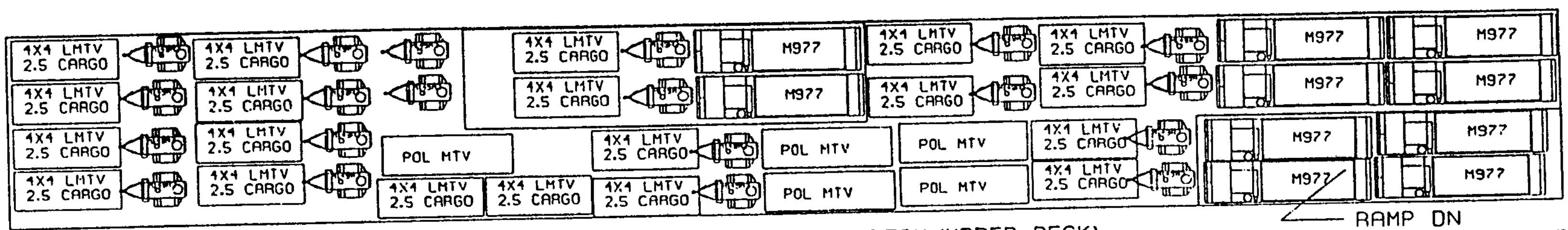
RAMP OVER HEAD RESTRICTED STOW



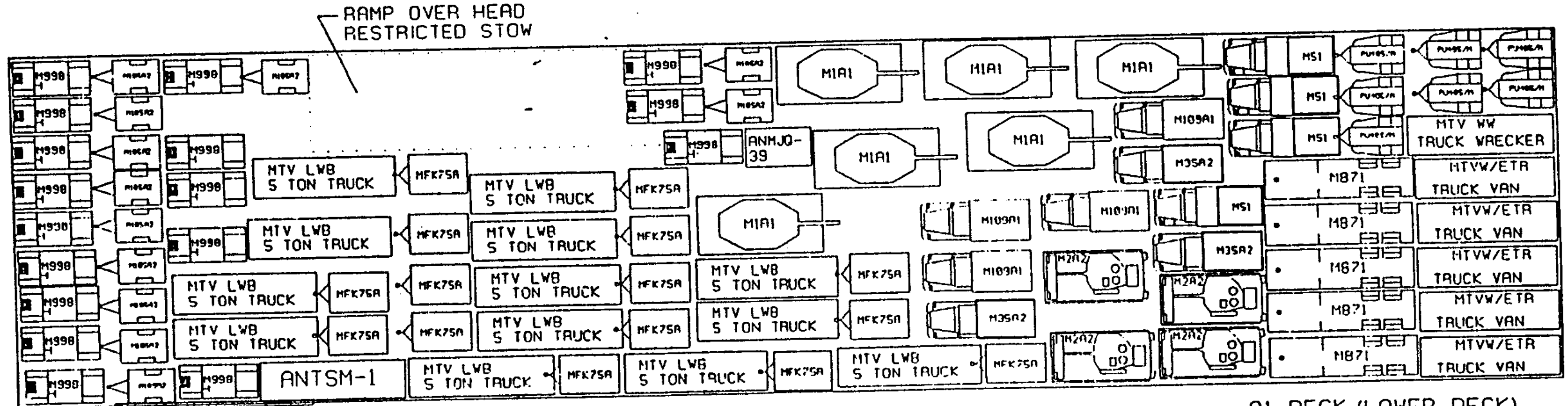
22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK

LOAD 5
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN



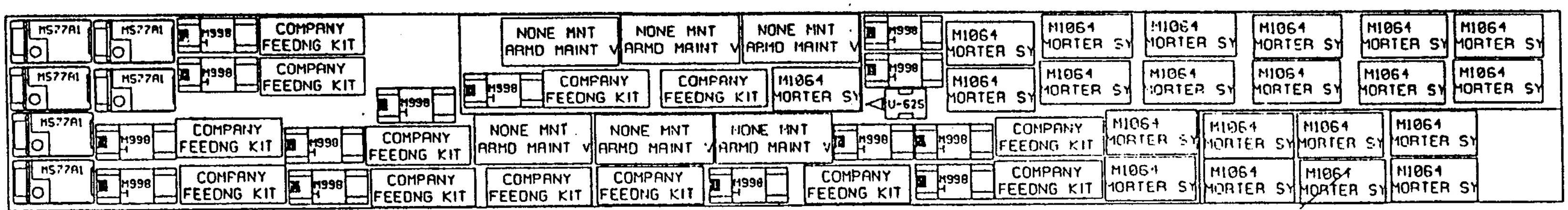
12129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK (UPPER DECK)



22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK (LOWER DECK)

LOAD 6
WINGSHIP
1725 TON PAYLOAD

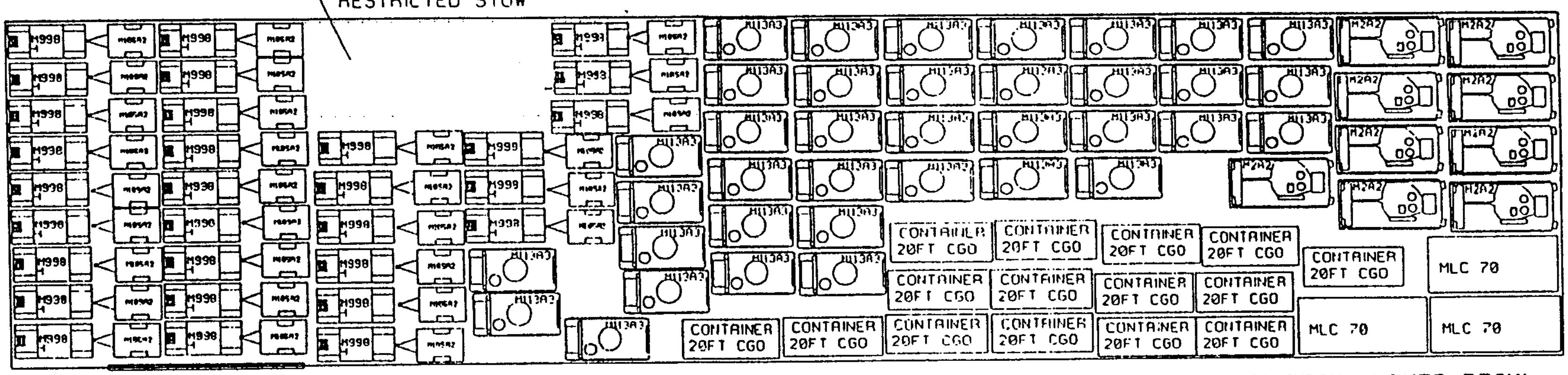
FORWARD RAMP DOWN



12129 SQ FT 311' X 39' 13'6" HEIGHT C1 DECK (UPPER DECK)

RAMP DN TO STERN RO/RO DOOR

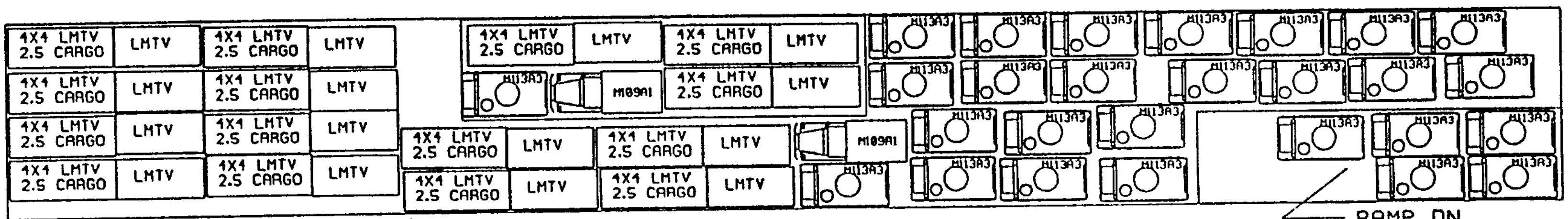
RAMP OVER HEAD RESTRICTED STOW



22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK (LOWER DECK)

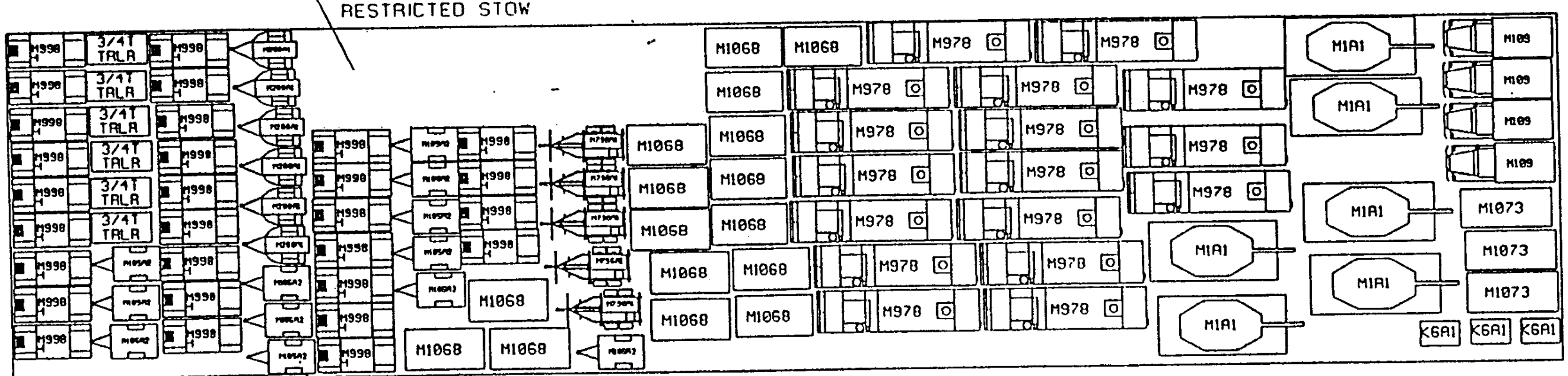
LOAD 7
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN



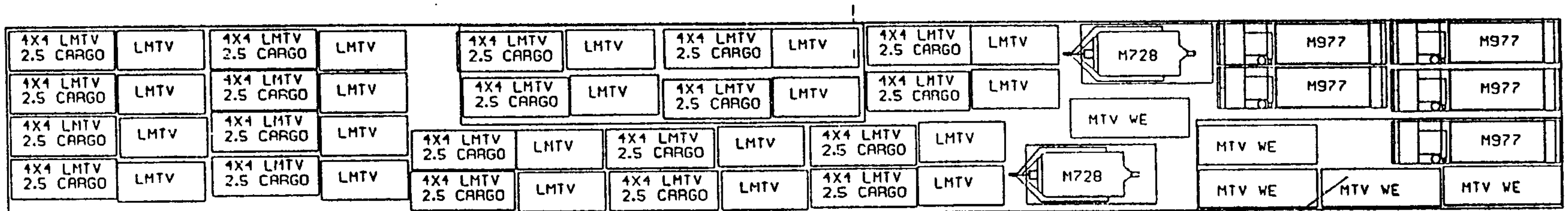
12129 SQ FT   311'X. 39'   13'6" HEIGHT   C1 DECK

RAMP OVER HEAD
RESTRICTED STOW

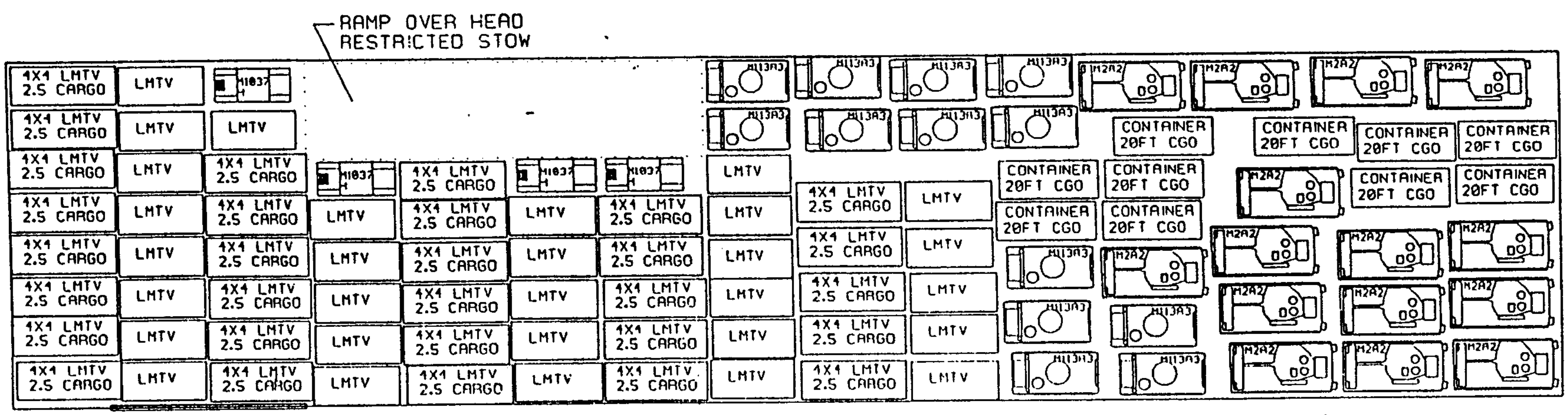


22752 SQ FT   316' X 72'   19'6" HEIGHT   A1 DECK

LOAD 8
WINGSHIP
1725 TON PAYLOAD



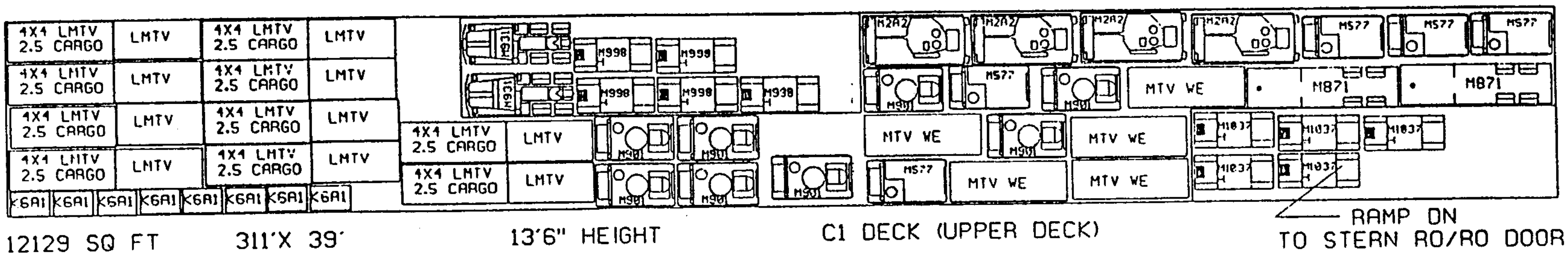
12129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK



22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK

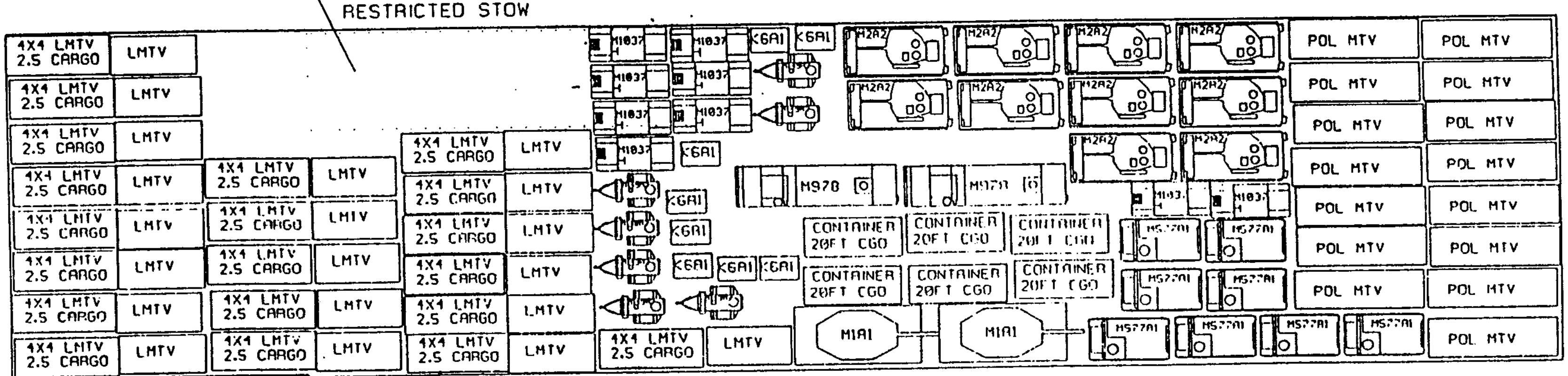
LOAD 9
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN



12129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK (UPPER DECK)

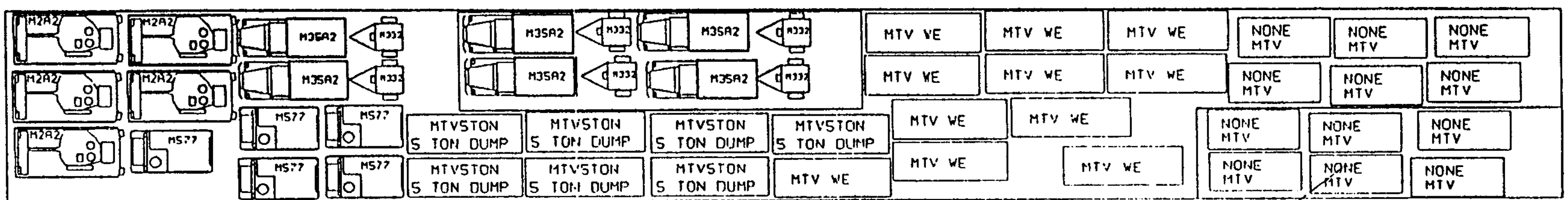
RAMP OVER HEAD RESTRICTED STOW



22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK (LOWER DECK)

LOAD 10
WINGSHIP
1725 TON PAYLOAD

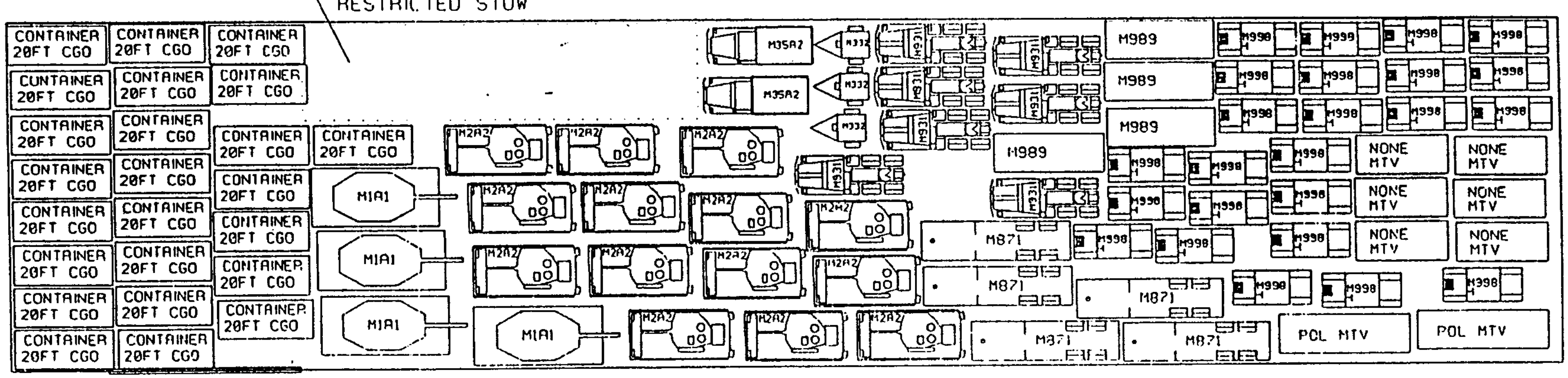
FORWARD RAMP DOWN



12129 SQ FT   311'X 39'   13'6" HEIGHT   C1 DECK (UPPER DECK)

RAMP DN
TO STERN RO/RO DOOR

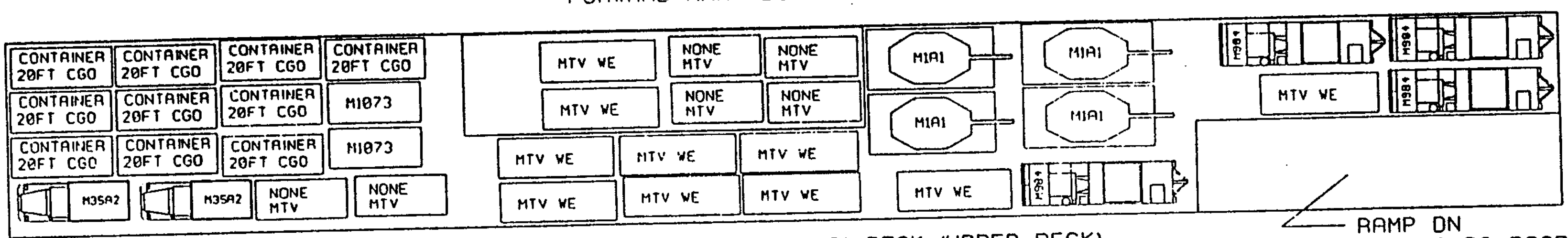
RAMP OVER HEAD
RESTRICTED STOW



22752 SQ FT   316' X 72'   19'6" HEIGHT   A1 DECK (LOWER DECK)

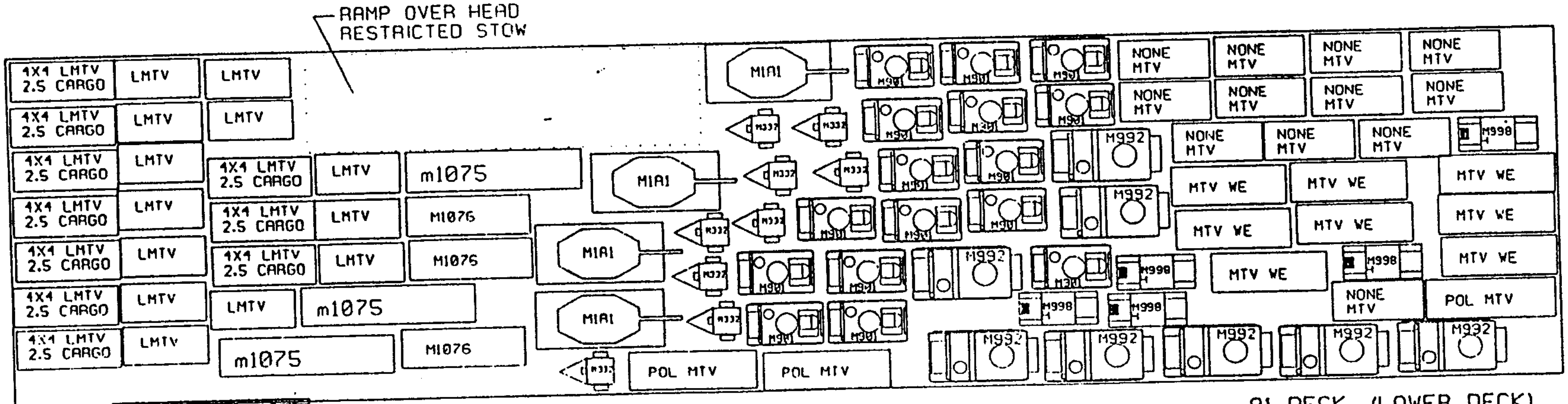
LOAD 11
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN



12129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK (UPPER DECK)

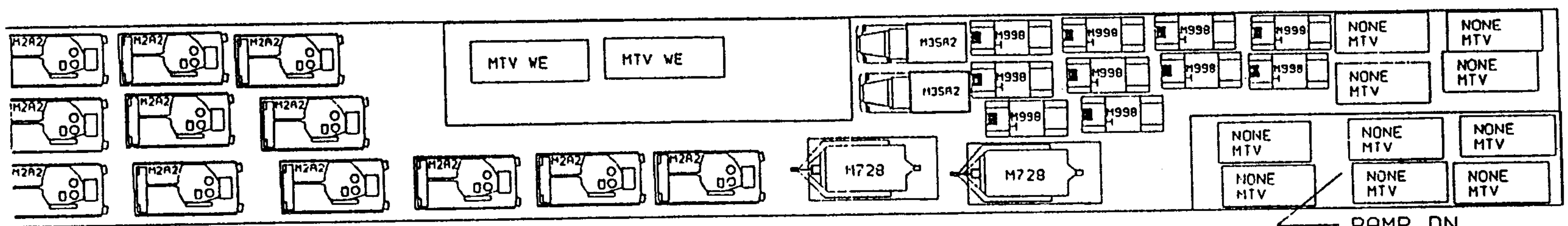
RAMP OVER HEAD RESTRICTED STOW



22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK (LOWER DECK)

LOAD 12
WINGSHIP
1725 TON PAYLOAD

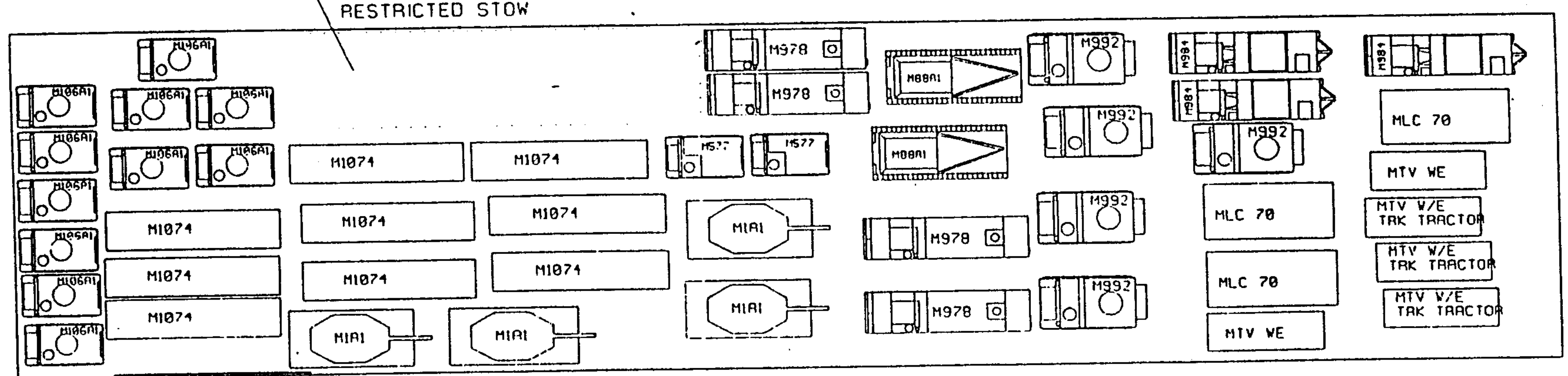
FORWARD RAMP DOWN



129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK (UPPER DECK)

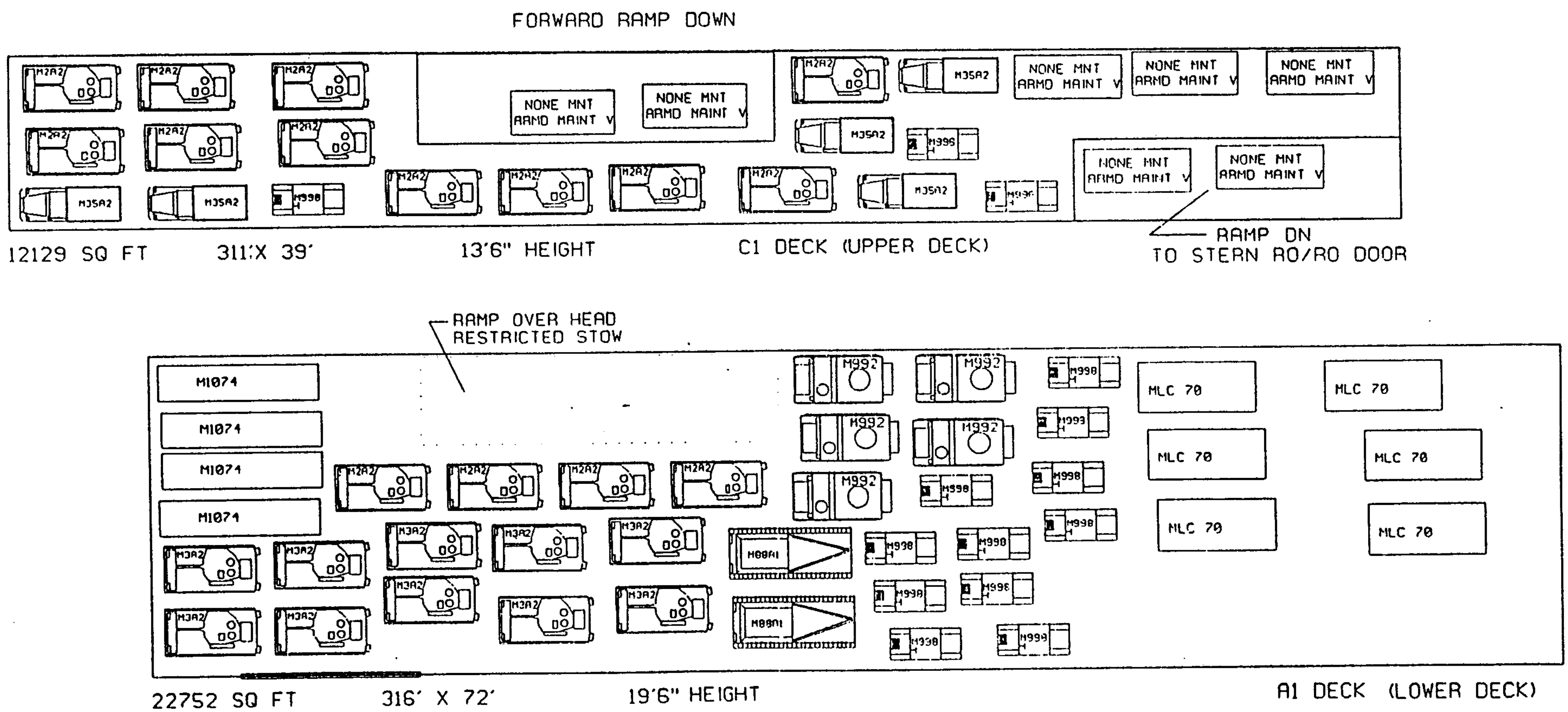
RAMP DN
TO STERN RO/RO DOOR

RAMP OVER HEAD
RESTRICTED STOW



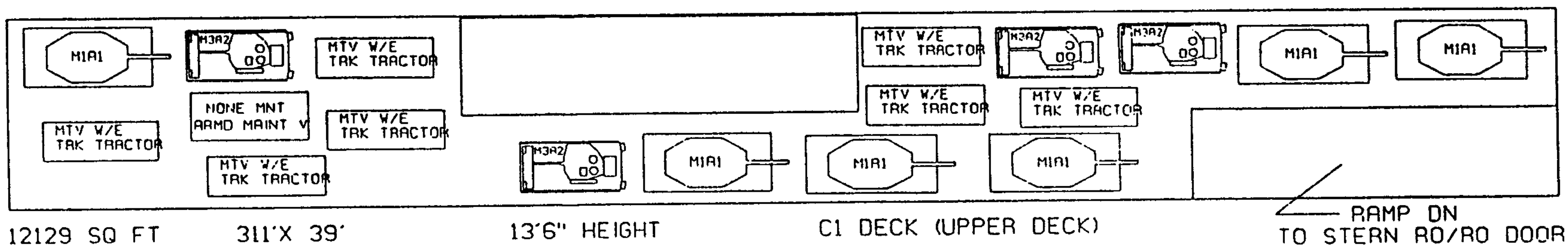
22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK (LOWER DECK)

LOAD 13
WINGSHIP
1725 TON PAYLOAD

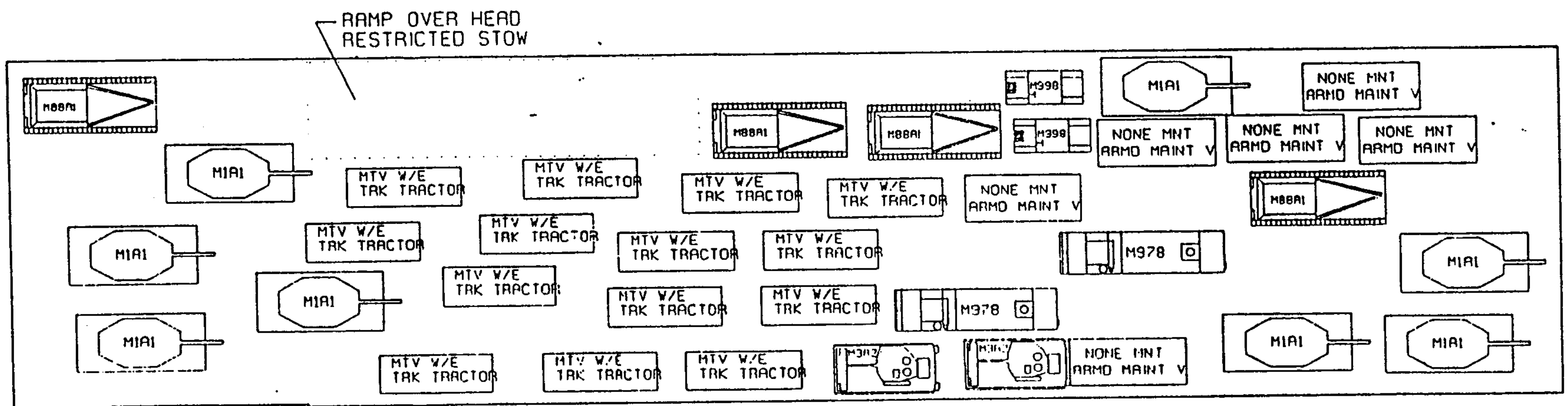


LOAD 14
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN

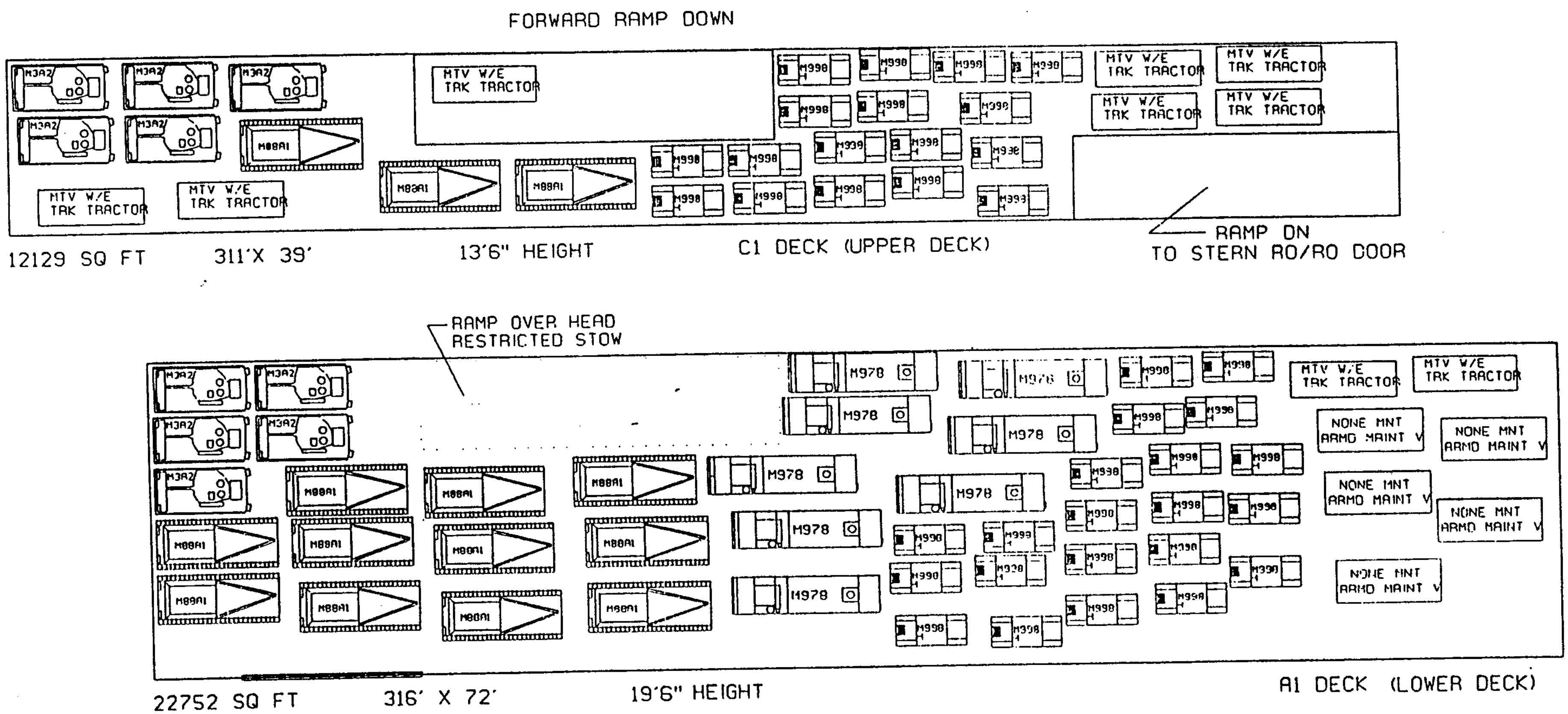


12129 SQ FT   311'X 39'   13'6" HEIGHT   C1 DECK (UPPER DECK)



22752 SQ FT   316' X 72'   19'6" HEIGHT   A1 DECK (LOWER DECK)

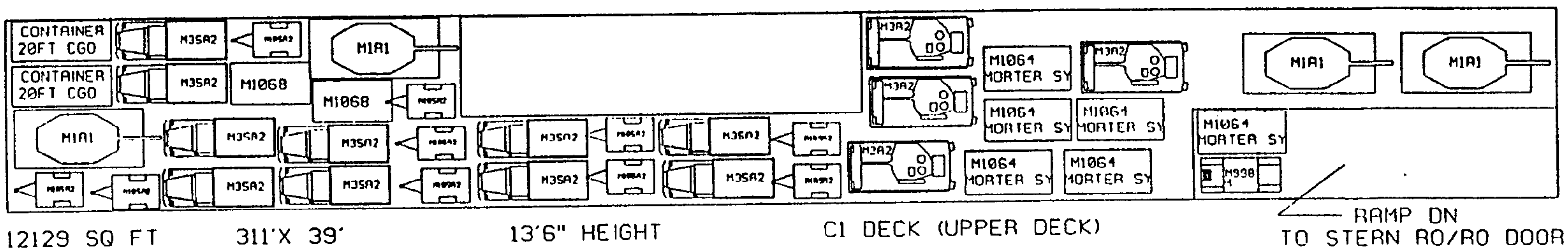
LOAD 15
WINGSHIP
1725 TON PAYLOAD



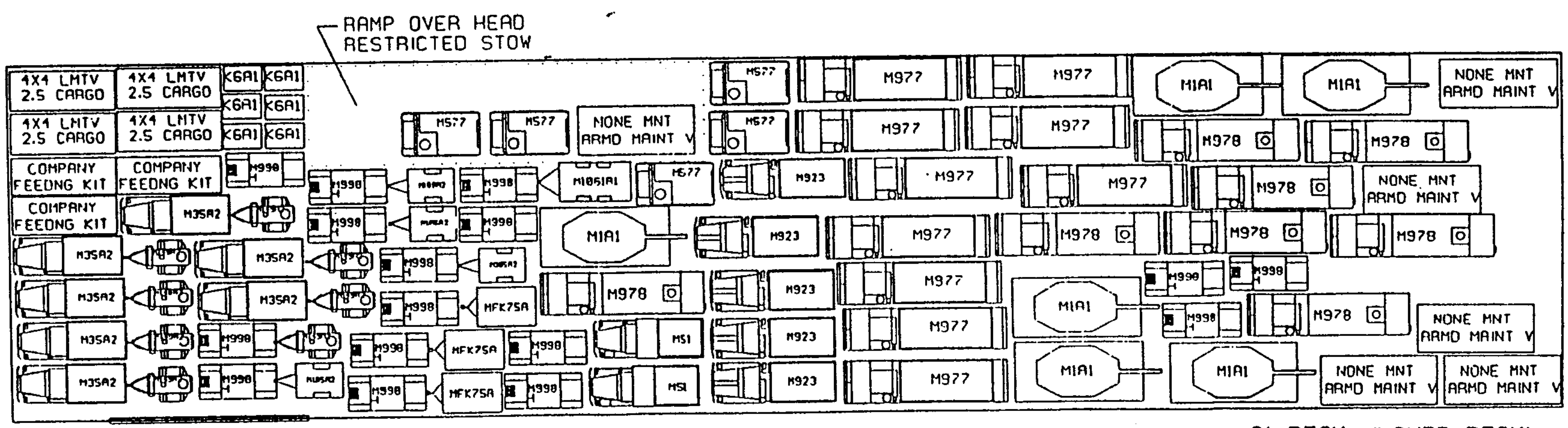
APPENDIX G
CODES STOW PLAN
TANK BATTALION
ON
1725-TON PAYLOAD WINGSHIP

TANK BATLN LOAD 1
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN



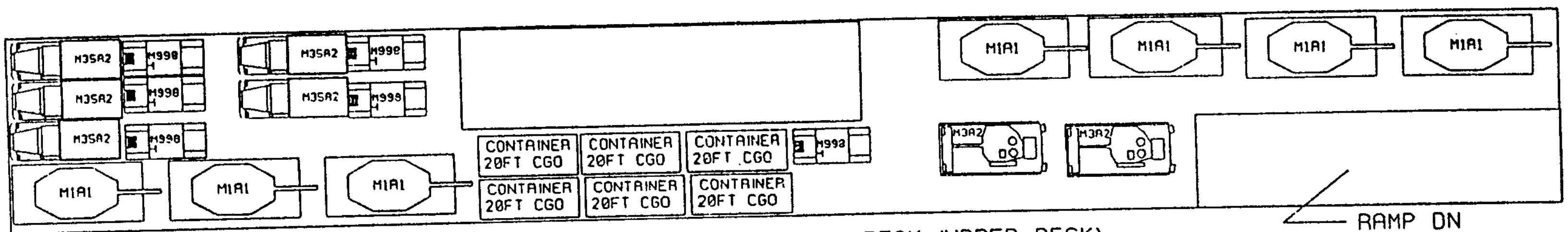
12129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK (UPPER DECK)



22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK (LOWER DECK)

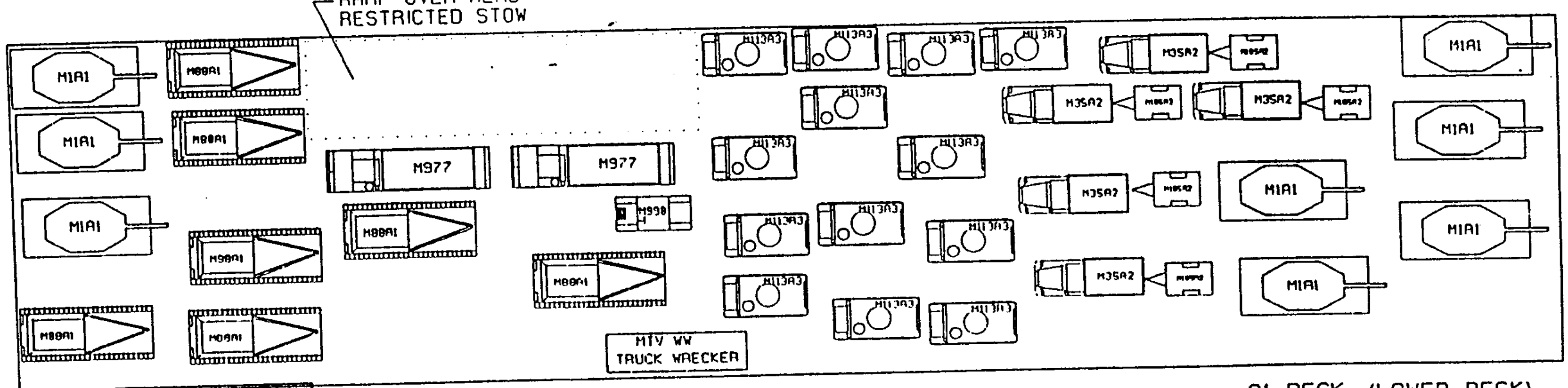
TANK LOAD 2
WINGSHIP
1725 TON PAYLOAD

FORWARD RAMP DOWN



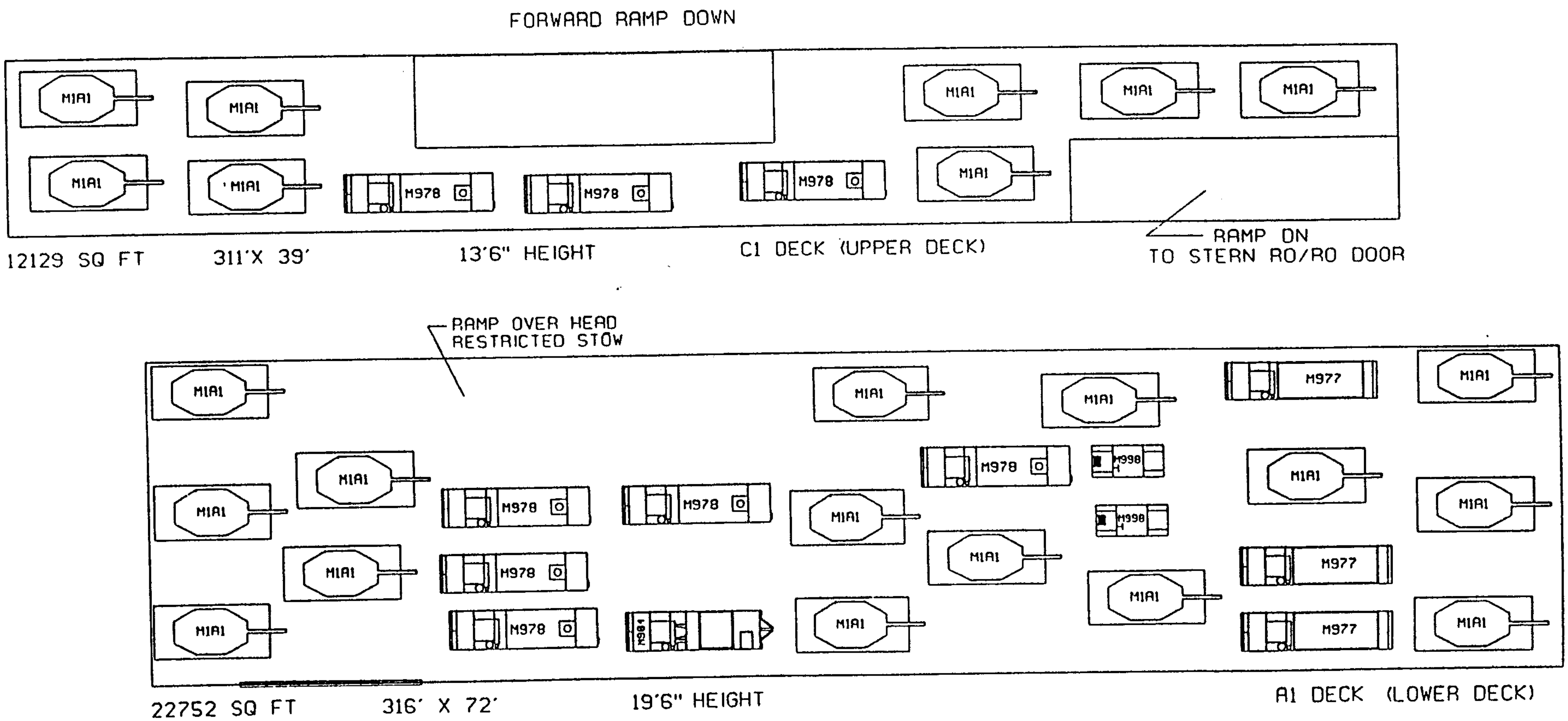
12129 SQ FT 311'X 39' 13'6" HEIGHT C1 DECK (UPPER DECK) RAMP DN TO STERN RO/RO DOOR

RAMP OVER HEAD RESTRICTED STOW

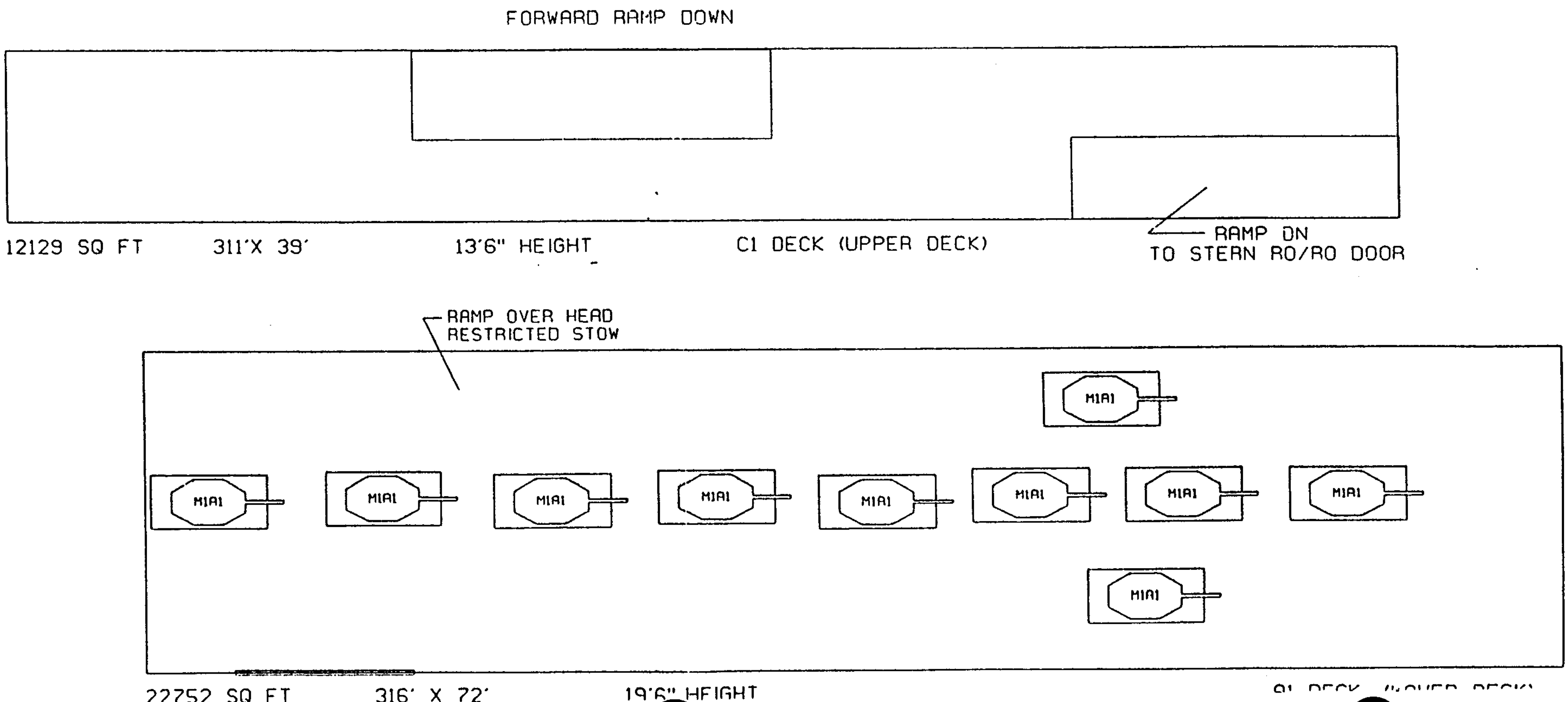


22752 SQ FT 316' X 72' 19'6" HEIGHT A1 DECK (LOWER DECK)

TANK LOAD 3
WINGSHIP
1725 TON PAYLOAD

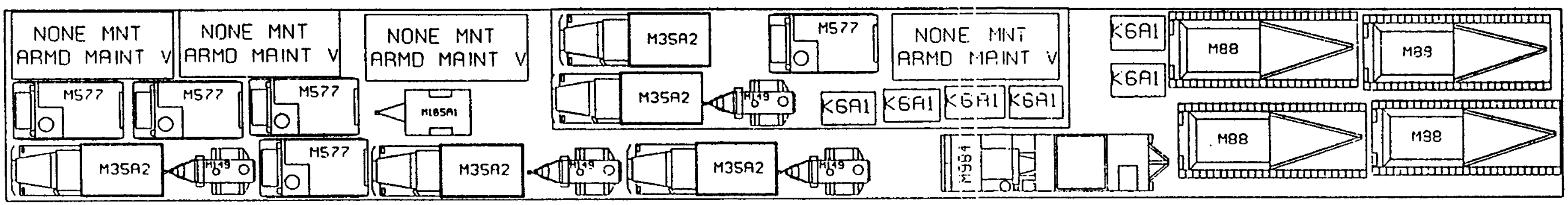


TANK LOAD 4
WINGSHIP
1725 TON PAYLOAD

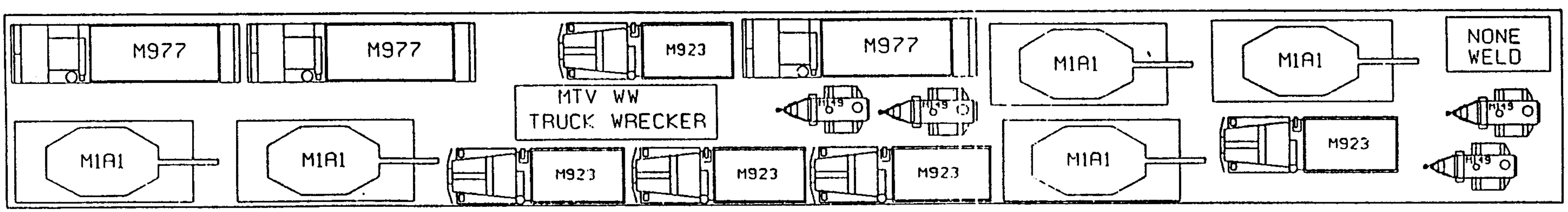


APPENDIX H
CODES STOW PLAN
TANK BATTALION
ON
900-TON PAYLOAD WINGSHIP

LOAD 1
WINGSHIP
900T PAYLOAD

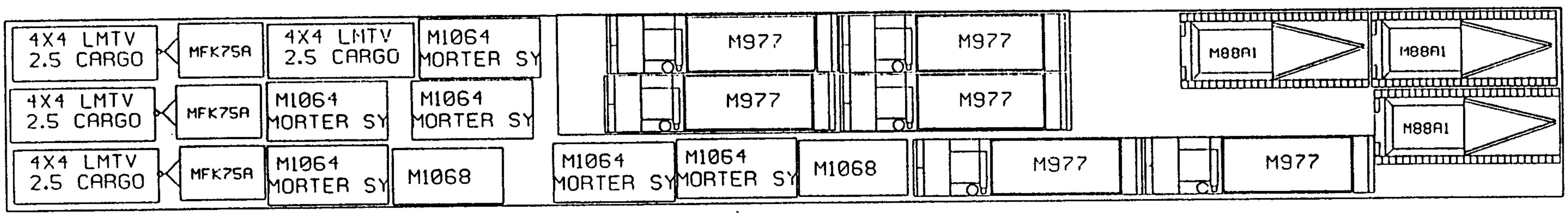


6426 SQ FT 226'3" X 28'4" 16' HEIGHT UPPER DECK

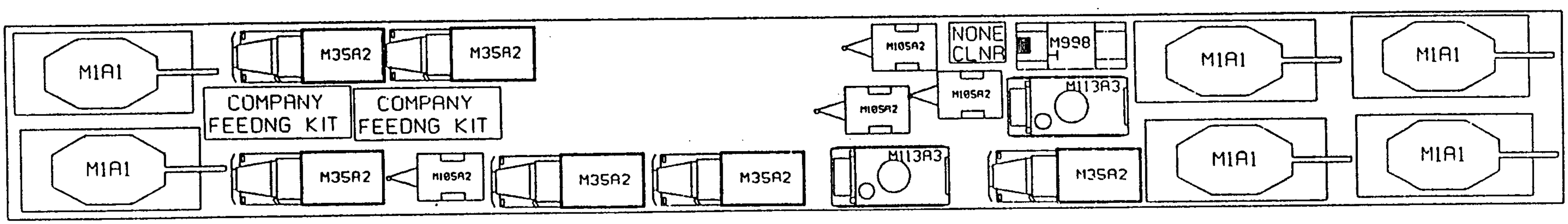


6426 SQ FT 226'3" X 28'4" 17' HEIGHT LOWER DECK

LOAD 2
WINGSHIP
900T PAYLOAD

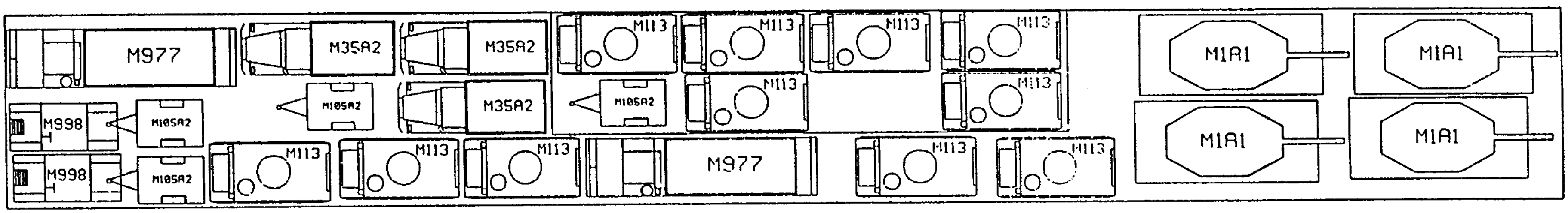


6426 SQ FT   226'3" X 28'4"   16' HEIGHT   UPPER DECK



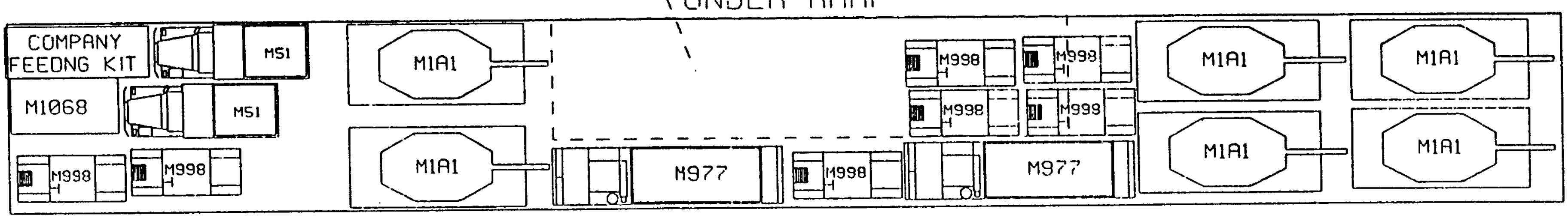
6426 SQ FT   226'3" X 28'4"   17' HEIGHT   LOWER DECK

LOAD 3
WINGSHIP
900T PAYLOAD



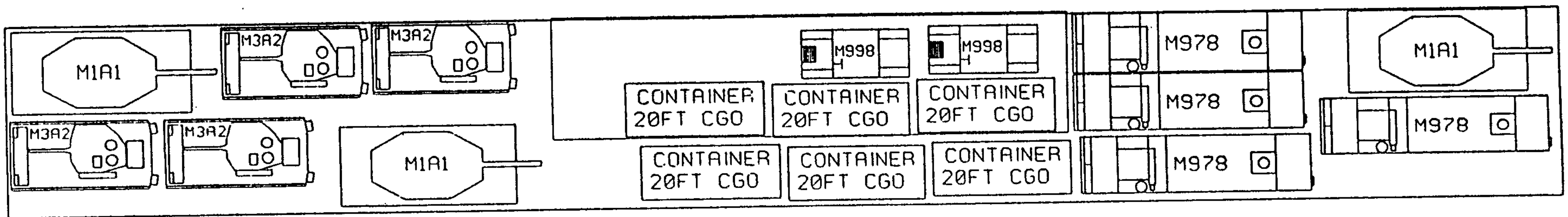
6426 SQ FT 226'3" X 28'4" 16' HEIGHT UPPER DECK

-RESTRICTED STOW AREA
UNDER RAMP



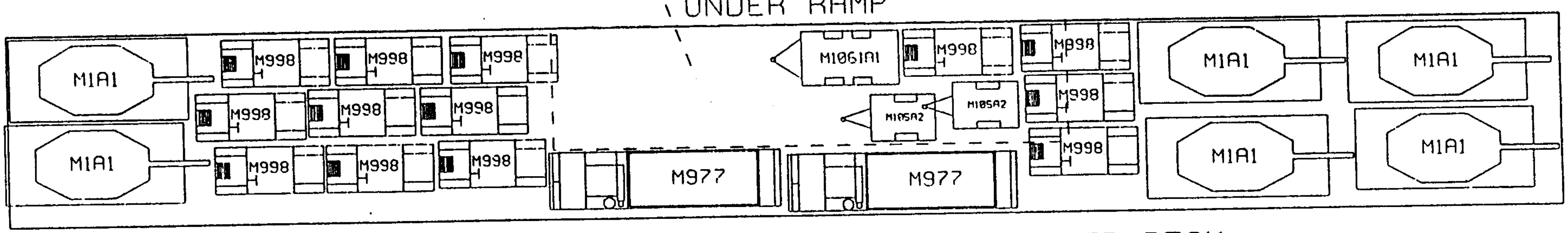
6426 SQ FT 226'3" X 28'4" 17' HEIGHT LOWER DECK

LOAD 4
WINGSHIP
900T PAYLOAD



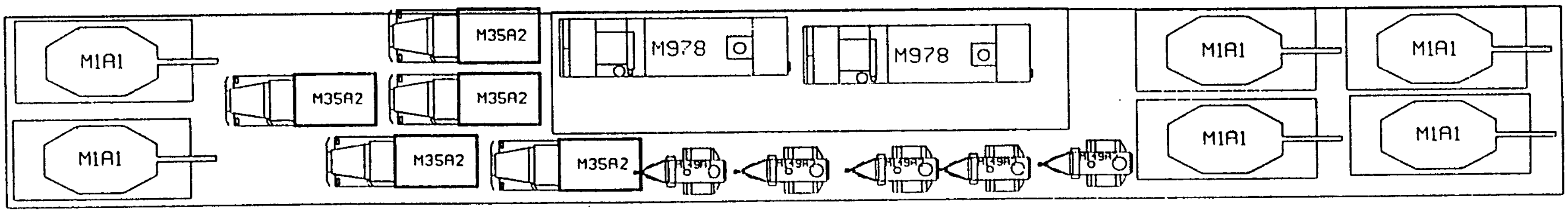
6426 SQ FT   226'3" X 28'4"   16' HEIGHT   UPPER DECK

-RESTRICTED STOW AREA
UNDER RAMP



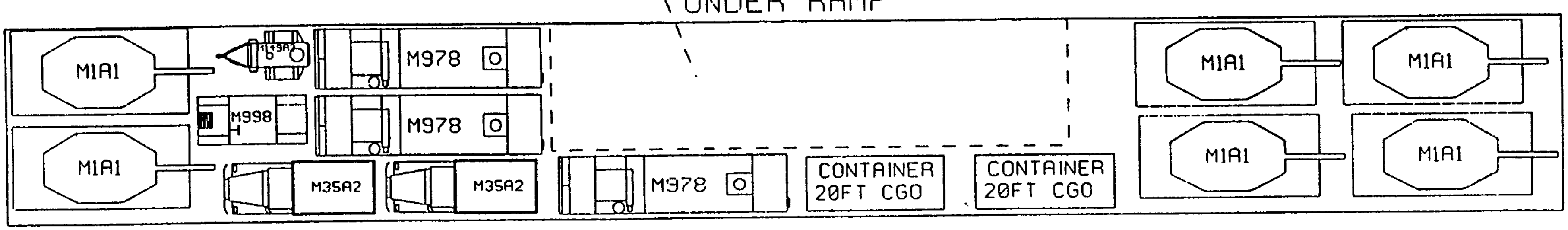
6426 SQ FT   226'3" X 28'4"   17' HEIGHT   LOWER DECK

LOAD 5
WINGSHIP
900T PAYLOAD



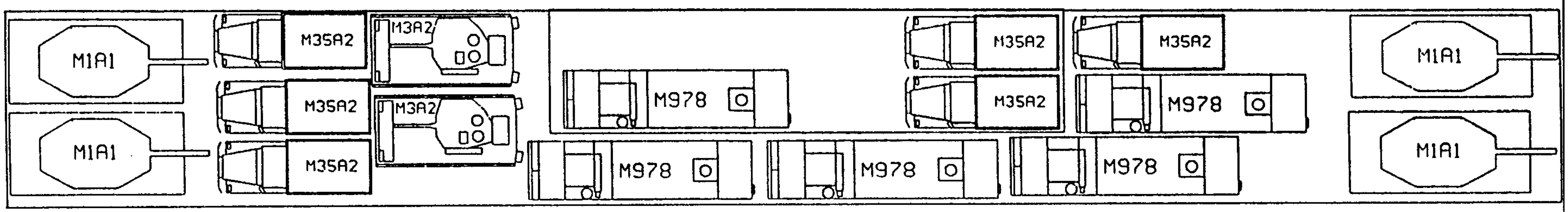
6426 SQ FT 226'3" X 28'4" 16' HEIGHT UPPER DECK

-RESTRICTED STOW AREA
UNDER RAMP

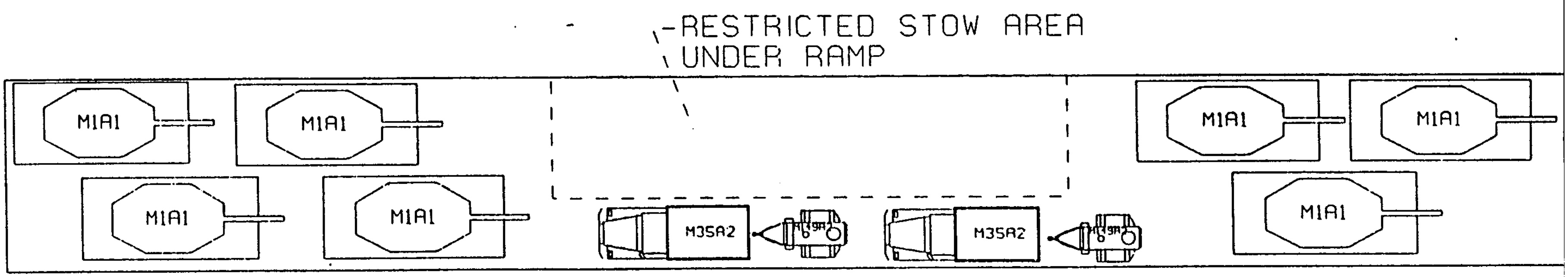


6426 SQ FT 226'3" X 28'4" 17' HEIGHT LOWER DECK

LOAD 6
WINGSHIP
900T PAYLOAD

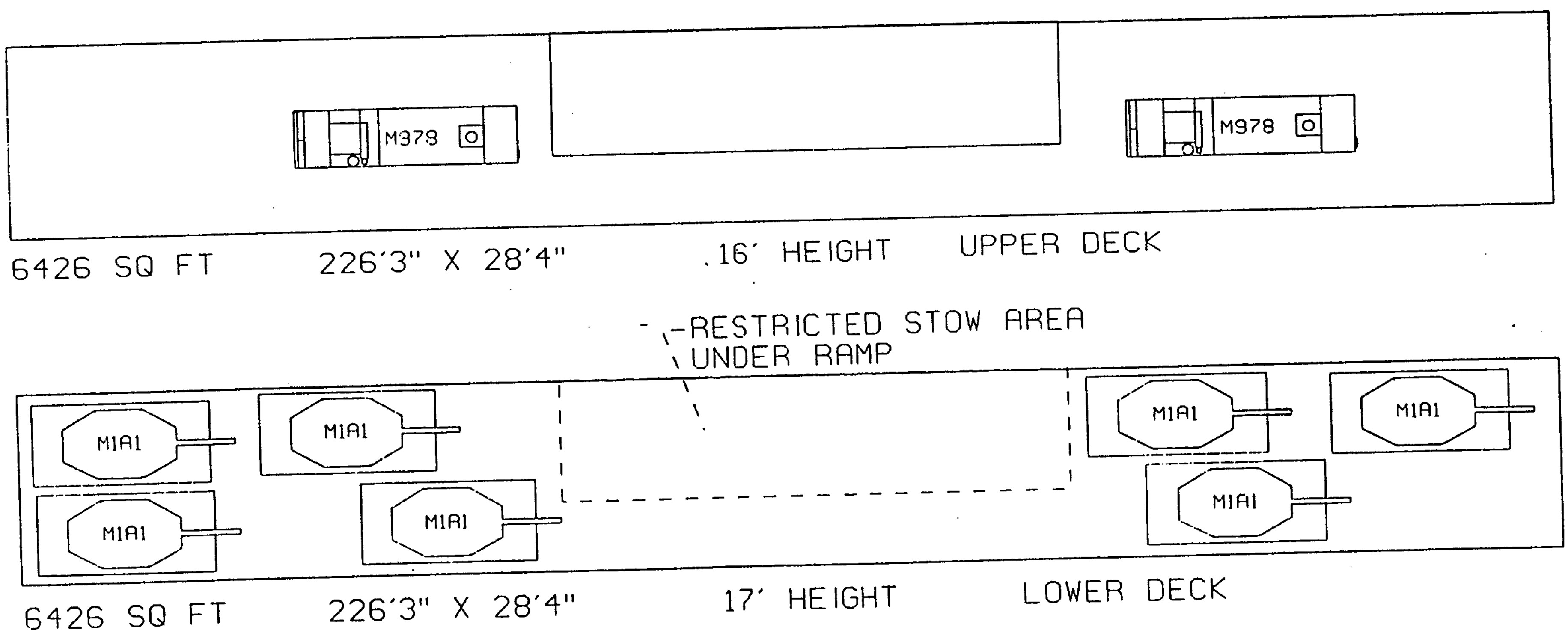


6426 SQ FT 226'3" X 28'4" 16' HEIGHT UPPER DECK



6426 SQ FT 226'3" X 28'4" 17' HEIGHT LOWER DECK

LOAD 7
WINGSHIP
900T PAYLOAD



Wingship Investigation

Propulsion

CONTENTS

Appendix K

SRS TECHNOLOGIES

SUITE 300
3900 NORTH FAIRFAX DRIVE
ARLINGTON, VIRGINIA 22203
(703) 528-2470
FAX # (703) 528-4715
WASHINGTON OPERATIONS

14 May 1993

Bob Hoenig
C/O Northrup Corp
8900 E. Washington Blvd Bldg 216
Pico Rivera, CA 90660-3737
FAX 310-948-9485

Dear Bob,

PWA's Dextrer Ramsey indicates that after my call, he should have sent you tabulated data on SFC vs Fnet at SL and 5K at 0.4 an 0.7 Mn, std day for the 82 or 84K Fnet version of the 4000 series - the PWA4084. If you FAX it to me, I can crunch you a curve fit. We'll have to do the installation losses separately - airframe bleed for ECS, etc.

Since I had the GE-90 tabular data, the equations for the curve fit I made for it at SL, 0.40 Mn are given below, for the ranges of Fn they apply to. This was done to find out how close a fit could be done with simple means suitable to a PC. One point in the extreme for each range was tested and the error was under 0.10% in all cases. Ought to fit any PC you've got.

RANGE A: (Fnet = 17869 to 30903 lbs)

$$\text{Log}_{10}\,(10\ \text{SFC}) = -0.23571\,(\text{Log}_{10}\ \text{Fnet}) + 1.71634$$

RANGE B: (FNET = 30904 to 47315 lbs)

$$\text{Log}_{10}\,(10\text{SFC}) = -0.077778\,(\log_{10}\ \text{Fnet}) + 1.00722$$

RANGE C: (Fnet = 47316 to 59514 lbs)

$$\text{Log}_{10}\,(10\text{SFC}) = +0.032836\,(\text{Log}_{10}\text{Fnet}) + 0.64744$$

Sincerely,

21 May 1993
055-93U/5461-70

Mr. Robert Hoenig
C/O Northrop Corporation
Adv Technology and Design Center
9900 East Washington Blvd. Bldg 21
Pico Rivera, CA 90660-3737

Dear Bob,

Pursuant to your FAX of the 18th, please find enclosed a set of tables defining corrected net thrust and specific fuel consumption for the PWA 4084. Initially, a logarithmic data fit was tried but was discarded because it was not linear except over small thrust increments. My interpretation of this is that it suggests realism in the PWA 4084 deck as it accounts for changing gas properties, component efficiencies and relocation of operating points for spool matching inside the various maps. Consequently, a tabular presentation was developed that adheres very closely to the PWA deck, as is explained below.

The presentation is made in three sets, for flight Mach numbers of 0, 0.4 and 0.7. Each presents (Fnet/delta ambient) in 2,000 lb increments from the smallest value identified previously by PWA up to the highest value given. (SFC/theta$^{0.5}$), with theta based upon fan inlet total temperature, is identified for each thrust value. SFC should be found by linear interpolation between two thrust points on the provided schedules. A schedule of the maximum thrust available as a function of fan inlet total temperature for Mach numbers of 0, 0.4 and 0.7, accurate to within 0.2%, is also provided. Stay within the temperature ranges shown unless PWA provides extending data.

A 24 point error analysis was conducted in which the tabular SFC data enclosed was compared against the PWA deck values for the lowest thrust value, the highest and one point in between at Mach 0, 0.4 and 0.7 for altitudes of 0, 3k and 5k. Linear interpolation was used between tabled points, just as described above. The absolute value of the max discrepancy of the tables compared against the deck as the standard was 0.56%, the minimum was 0.01% and the average was 0.22%.

The tables were developed as follows. The PWA deck was generalized to one line for each Mach number, regardless of altitude or inlet temperature, using the SL and 5K ft deck data by the use of delta ambient (altitude static pressure,

PSF/2116) and square root of theta (fan inlet total temperature, $^{o}R/518.7)^{0.5}$. The plot of these is presented in figure 1 and shows good correlation of the deck from SL to 5K at any one Mach number despite temperature and altitude changes. This generalization was sought so you could do climb, descent and cruise through an altitude range from SL to 5K even with non-standard temperatures (inside the ranges shown) and get precise fuel burnoffs for various climb rates.

The Fnet/delta amb vs SFC/(theta)$^{0.5}$ values were plotted in figure 1 using the 8 or so points provided by PWA at SL and 5K for each Mach number. The generalized SFC was then read off at thrust increments of 2,000 lbs which provided 20 to 30 points for each Mach number. These values went into the tables and the error analysis previously identified at SL, 3K and 5K.

Since you indicated that accessory bleed and power extraction for the ECS would be provided by an on-board APU, please be advised that the Russian "Orlenok" gets her electrical power, vehicle pneumatic air supply and engine starter air from multiple TA-60 APUs, weighing 300 kgs (dry) each. Their "Loon" uses GTG-100's. How many are used is not clear to me.

A duct burning model/tables will be developed for you shortly.

Sincerely,

Eric Lister
Chairman, Wingship
Propulsion Sub-Committee

TABLE OF CORRECTED NET THRUST VS SPECIFIC FUEL CONSUMPTION
PWA 4082 - SL to 5,000 FT ALTITUDE

TABLE 1 - 0 Mach number

Fnet/delta amb, lb	**SFC/(theta total)$^{0.5}$, per hr**
88000	0.3300
86000	0.3255
84000	0.3215
82000	0.3170
80000	0.3135
78000	0.3100
76000	0.3070
74000	0.3040
72000	0.3025
70000	0.3005
68000	0.2990
66000	0.2980
64000	0.2970
62000	0.2950
60000	0.2940
58000	0.2925
56000	0.2915
54000	0.2900
52000	0.2880
50000	0.2870
48000	0.2850
46000	0.2845
44000	0.2835
42000	0.2825
40000	0.2820
38000	0.2818
36000 - 22000	0.2818

TABLE OF CORRECTED NET THRUST VS SPECIFIC FUEL CONSUMPTION
PWA 4082 - SL to 5,000 FT ALTITUDE

TABLE 2 - 0.4 Mach number

Fnet/delta amb, lb	**SFC/(theta total)$^{0.5}$, per hr**
62000	0.4620
60000	0.4590
58000	0.4570
56000	0.4550
54000	0.4545
52000	0.4535
50000	0.4530
48000	0.4530
46000	0.4535
44000	0.4540
42000	0.4550
40000	0.4560
38000	0.4575
36000	0.4600
34000	0.4630
32000	0.4660
30000	0.4700
28000	0.4745
26000	0.4800
24000	0.4865
22000	0.4945
20000	0.5040
18000	0.5150
16000	0.5290
14000	0.5450
12000	0.5650

TABLE OF CORRECTED NET THRUST VS SPECIFIC FUEL CONSUMPTION
PWA 4082 - SL to 5,000 FT ALTITUDE

TABLE 3 - 0.7 Mach number

Fnet/delta amb, lb	**SFC/(theta total)$^{0.5}$, per hr**
54000	0.5660
52000	0.5665
50000	0.5670
48000	0.5680
46000	0.5695
44000	0.5710
42000	0.5735
40000	0.5760
38000	0.5800
36000	0.5835
34000	0.5885
32000	0.5950
30000	0.6035
28000	0.6135
26000	0.6250
24000	0.6370
22000	0.6490
20000	0.6650
18000	0.6845
16000	0.7140

CORRECTED MAX AVAILABLE THRUST VS INLET TEMP
PWA 4082 - SL TO 5,000 FT

TABLE 1A

MACH NUMBER	MAX FNET/DELTA AMB, LBS	FITT, °F
0	87100	40
0	86680	42
0	86260	44
0	85840	46
0	85420	48
0	85000	50
0	84580	52
0	84160	54
0	83740	56
0	83320	58
0	82900	60

OR USE [MAX FN/DELTA AMB = -210 x FITT + 95500]
FOR FAN INLET TOTAL TEMPS BETWEEN 40 AND 60 °F.

TABLE 2A

MACH NUMBER	MAX FNET/DELTA AMB, LBS	FITT, °F.
0.40	61113	54
0.40	60887	56
0.40	60661	58
0.40	60435	60
0.40	60209	62
0.40	59983	64
0.40	59757	66
0.40	59530	68
0.40	59304	70
0.40	59078	72
0.40	58852	74
0.40	57164	76
0.40	55477	78

OR USE [MAX FNET/DELTA AMB, LBS = -113 x FITT + 67215],
FOR 55 to 74 °F. FITT
AND [MAX FNET/DELTA AMB, LBS = -843.8 x FITT + 121293]
FOR 74 to 78 °F. FITT

TABLE 3A

MACH NUMBER	MAX FNET/DELTA AMB, LBS	FITT, °F.
0.70	54180	90
0.70	53726	92
0.70	53272	94
0.70	52818	96
0.70	52364	98

0.70	51910	100
0.70	50602	102
0.70	49294	104
0.70	47986	106
0.70	46678	108
0.70	45370	110

OR USE [MAX FNET/DELTA AMB = -227 x FITT($^{\circ}$F) + 74610]
FOR 90 to 100 $^{\circ}$F FITT
and [MAX FNET/DELTA AMB, LBS = -654 x FITT($^{\circ}$F) + 117310]
FOR 100 TO 110 $^{\circ}$F FITT.

18 June 1993
060-93U/5461-70

Mr. Robert Hoenig
C/O Northrop Corporation
Adv Technology and Design Center
9900 East Washington Blvd, Bldg. 21
Pico Rivera, CA 90660-3737

Dear Bob,

In order to support Northrup's Wingship study efforts to explore the effects of unique technologies upon mission performance, an assessment of the performance of a large turbofan with a fan duct burner for thrust augmentation was undertaken here. The baseline engine used for the effort here was a PWA 4084 rated at 83079 lbs of thrust at SLTO, std day. The objective was to develop the impact of a fan duct burner upon total thrust, fuel flow and duct discharge temperature. It is suggested that one desired benefit to seek in your study is the effect of using a duct augmentor as a means of keeping the high takeoff and landing thrust requirement from oversizing the engines for cruise. If successful, fewer engines would be required and at cruise, the sfc would be minimized by virtue of having each engine operating at a higher percentage of available thrust. With the duct burner, drag at cruise would also be substantially reduced because engines would not have to be shut down and windmilled, as is currently envisioned for non-augmented fans.

The performance values are identified in the following empirical equations and on the attached curves for varying degrees of duct burning at sea level static standard day conditions and no others. The curves and equations are presented without explanation so you could easily input them to a PC. However, they were based upon conventional propulsion concepts for thrust in an unchoked nozzle as a function of stream Mach number and acoustic velocity plus a heat balance for the duct burner. As indicated on the curve, the predictions are based upon informal information from PWA indicating that the fan pressure ratio is approximately 1.6 and the dry thrust split between the fan and core streams is in the ratio of 83%/17%. The equations are:

1. Fg, lbs = 2844.74 $(T_{t5,\ Deg\ R})^{0.5}$ + 14130.6
   . where Fg is total fan duct + core gross thrust
   $T_{t5,\ Deg\ R}$ is duct burner discharge temp at nozzle
2. Wf, lbs/hr = 137.83 $(T_{t5\ Deg\ R})$ - 57001
   . where Wf is total fan duct + core fuel flows, lbs/hr.

[*Note added 9/20/93 - Information from PWA after this letter was written suggested that although the thrusts predicted were*

consistent with theirs for the fan out temperature, the fuel flows abopve were about 8% high. Accordingly, Hoenig of Northrup was sent a FAX by the writer and asked to reduce all fuel flow values by about 8%.]

Duct burner discharge temperature was selected as the parameter to drive both thrust and fuel flow changes because it will be limited by what the wing structure can sustain downstream of it in the Wingship PAR concept. While the titanium in the wing may not be tolerant of any structural members getting beyond 800 ^oF (1260 ^oR), there are two factors which may drop the engine exhaust flow stagnation temperatures at the wing, which is why values were developed out to 1000 ^oF T_{t5} at the nozzle. One is that some modest downstream plume mixing with ambient air is likely and the second is that several sources (including the Russians) suggest there is a strong flow of outside air coming over the wing leading edge from entrained flows or Coanda effect. I regret I am not able to define these dilution effects at this time with any certainty. However, to assist you, I will request help on those two effects from other committee members (Hooker and Covert) and will get back to you at the first convenience if they can help on this. In the meantime, you might wish to consider 800 ^oF as the max T_{t5} value practical for the problem, which puts max TO thrust at 115109 lbs, when the max dry value is 83079 lbs for an augmentation ratio of 1.386. The corresponding fuel flow value is 116665 lbs/hr. If the T_{t5} value can be driven up to 1460 ^oR, then an augmentation ratio of 1.478 could be achievable on the same 83079 lb dry thrust engine.

The remaining feature of the engine to be discussed is how to easily vector the thrust down under the wing. The Naval Air Warfare Center at Trenton and Dr. Covert from MIT indicate that the fan nozzle and the core nozzle are probably both unchoked at SLTO. If this is the case, then the two streams can be allowed to mix and interact before leaving the engine without concern for stalling either one since both will be at the same static pressure in the nozzle throats. This would permit the fan duct to be extended to the rear of the engine for the use of a single axis deflected thrust nozzle. The design however would not allow for augmented thrust much beyond takeoff/landing speeds for fear of inducing fan/core stall owing to the nozzles becoming choked as flight speed was increased. Thus, the fan duct burner becomes strictly a device for takeoffs and landings. The other capability the nozzle system might need for stall free operation would be the ability to keep the fan nozzle throat far enough forward in flight to keep fan and core streams from mixing before discharge. The fan nozzle might therefore have to be deflectable, both a closed and an open area position, translatable and possibly non-circular to promote external mixing. Thus the duct burner becomes a definite technology piece if it is worthwhile to the mission, which is indeed what the Wingship committee seeks to determine. I'll try to provide more on this as it is developed, but for right now let's assume that the fan duct/nozzle will do all of the above

in lieu of more complex schemes with substantial drag and weight penalties.

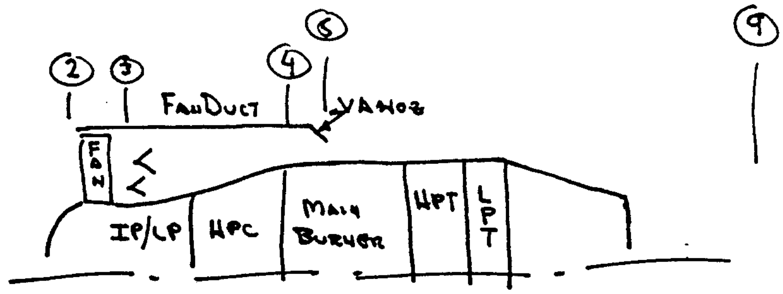
I still owe you some installation factors and details for the inlet and exhaust systems and will try to get to them over the next few weeks.

Please advise if you have questions on any of the information transmitted in this letter.

Sincerely,

Eric Lister
Chairman, Wingship
Propulsion Sub-Committee.

CC:
. Len Malthan
. Roger Gallington
. Gene Covert
. Steve Hooker
. Robt. Wilson
. John Fraas
. SRS File



1. THRUST - CHOKED NOZZLE

$$F_{gross} = A_5 \left\{ P_{T_5} \left(\frac{2}{\gamma+1}\right)\gamma \left(\frac{2}{\gamma+1}\right)^{\frac{1}{\gamma-1}} + P_{T_5}\left[1+\left(\frac{\gamma-1}{2}\right)^{-\gamma/\gamma-1}\right] - P_{s9} \right\}$$

for $\gamma_5 = 1.3565$

$$F_g = A_5 \left\{ 1.2624\, P_{T_5} - P_{s9} \right\} = A_5 P_{s9} \left\{ 1.2624 \left(\frac{P_{T_5}}{P_{s9}}\right) - 1 \right\}$$

2. FOR MASS FLOW, AREA - CHOKED NOZZLE

$$\frac{W_{g5}\sqrt{T_{T5}}}{A_5 P_{T5}} = \text{CONSTANT}, C_1 \Big\} \text{ FOR FIXED OPERATING POINT ON FAN MAP,}$$

$$\left.\frac{W_{a_3}\sqrt{T_{T3}}}{A_5 P_{T3}}\right|_{DRY} = \text{CONSTANT}, C_1, \text{ CHOKED NOZZLE AT } 5$$

$$\frac{A_{5_{WET}}}{A_{5_{DRY}}} = \frac{W_{g5}}{W_{a_3}} \cdot \frac{P_{T3}}{P_{T_5}} \cdot \sqrt{\frac{T_{T5_{WET}}}{T_{T3_{DRY}}}} \approx \sqrt{\frac{T_{T5_{WET}}}{T_{T3_{DRY}}}}$$

THUS
$$\frac{F_{g_{WET}}}{F_{g_{DRY}}} \approx \frac{A_{5_{WET}}}{A_{5_{DRY}}} \approx \sqrt{\frac{T_{T5_{WET}}}{T_{T3_{DRY}}}}$$

30 July 1993
063-93U/5461-70

Mr. Robert Hoenig, N212/XA
C/O Northrop Advanced Technology and Design Center
PO Box 158
Pico Rivera, CA 90660-0158

Dear Bob,

Enclosed please find my rough estimates for the physical layout of a high by-pass turbofan in the 83079 lb static thrust class. It would be approximately 114 inches in diameter to the outer fan case (with a nacelle thickness of about one foot more than that). The length from bullet nose to tip of the tailcone would be at least 312 inches long, which is not far from the 325 inch value I have heard casually from PWA. Dry weight would be 14,000 lbs which might get 10% lighter if the thrust reversing system is removed.

Also enclosed is a weight breakdown on a one stage augmentor, limited to no less than 800 deg F and possibly as high as 1000 deg F. The burner might be located in the last 6 feet or so of augmentor duct length. It has a 20 deg down deflecting thrust, two area position nozzle and must translate forward once flying speed is attained in order to keep the fan and core streams from mixing as the nozzles begins to choke. It has two sets of actuators for translation plus area changes although PWA might be able to design a linkage set that would accomplish both requirements simultaneously with only one actuator set. The material used in the assessment was Ti matrix composite with a density of roughly 0.16 lbs/cubic inch vice Ti alloy which is only 0.12. A matrix composite was envisioned because it has nearly double the strength properties of Ti alloys which seem to hold to at least several hundred degrees F more than the Ti alloys. Note that the augmentor/fan duct in this configuration is about 23 ft. long and it is estimated to weigh 2183 lbs, which is in addition to the 14,000 lb dry engine weight. The augmentor weight is everything that would be needed in the augmentor system but does not include any weight adders to the fan frame to carry augmentor axial and shear loads or deflected thrust moments.

The major loads in the augmented deflected mode when the fan thrust alone was 101,000 lbs (1.38 overall engine aug ratio) were: (1) vertical shear- 35,0000 lbs, and (2) bending moment at the fan discharge - 800,000 ft lbs. An anti-screetch liner was included to avoid combustion instability problems. These loads posed no problems in combined flexure and shear for a 16 gauge outer duct (principal stress under 20,000 PSI), so the mechanical integrity of Ti composites from the standpoint of just these loads would be

very high. However, this assessment did not consider buckling from axial thrust column loads on the augmentor nozzle (from MV and A*delta P forces) nor the contribution to buckling that would be present from the 35,000 lb transverse load when in the deflected thrust position. PWA should be asked to comment on what the likely weight might be.

PWA would likely also have to re-examine their fan case and strut design to see how it's deflections would bear up under the above shear and moment, since fan blade tip clearances must be maintained despite the problems of holding the augmentor weight and deflected thrust loads.

If your design studies indicate that a fan duct burner augmentor would be useful to the wingship mission, I would like to emphasize that such an augmentor would be a genuine technology challenge. In addition to being a difficult burner owing to low pressures and temperatures, it would require not only a deflecting thrust nozzle but one that somehow keeps fan and core streams from mixing once past takeoff speed. A translating nozzle is one solution, but PWA may have others. It may also benefit from the use of Ti matrix composites, which are relatively new and carry their own uncertainties.

Sincerely,

Eric Lister
Chairman, Wingship
Propulsion Sub-Committee

[Note added 9/20/93 *- the scheme of a translating augmentor duct and a deflecting thrust nozzle was dropped as a candidate devevlopment concept for American Wingships (but a short duct burner was retained). This was done as a result of speaking with the Russians in August whose first choice was to mount the engines on a canard and rotate the engines. Since their first choice coincided with mine, the above scheme was dropped in favor of a relatively short fan duct augmentor and rotating the canard.]*

The Ruissians also said that they have been trying for some time now to use thrust augmentation, but with a wet wing for PAR, they were limited to 220 deg C., the value for hot surface ignition of JP fuels. They gave no indication that they were trytng to find ways to either make the fuel non-combustible (like nitroigen inerting) or reduce it's temperature rise during the 1-2 minute takeoff period.]

Estimated Augmentor System Weights

Primary Materials - Ti and Ti composite matrix

Component	Weight, Lbs.	
o Outer case	1000	
o Inner screetch liner		600
o Nozzle flaps	160	
o 3 zone Vee gutters & supports		30
o Liner attachments	20	
o Fuel spray bars (60)	30	
o Fuel lines	30	
o Fuel manifold		30
o FADEC	20	
o A/B pump	40	
o Sensors & lines	10	
o Flap actuators (6)		60
o Duct traverse actuators (6)	60	
o Traverse actuator hyd. lines	25	
o Flap actuator hyd. lines		25
Total		2140
2% Development adder	43	
Grand total	2183 lbs/engine	

Engines as a Source of "Special Environmental Considerations"

o One Big Issue - are there salt water ingestion effects by hydrocarbon combustion systems that can produce Dioxin ($C_{12}H_4O_2CL_4$)?? The Chlorine comes from NaCl in sea water. The tradeoff may be the health of local people, crew members and passengers. The issue, if it is real, could be a sure fire show stopper until it is understood and defeated.

o A Second Possibly "Big Issue" - the noise level on takeoff as defined above will have to be identified and addressed in order to operate on US coasts/ports during development, training or operation. The crux will be local rules, not federal. The Mayor of Oxnard can prevent operations in his area if noise is above his threshold.

Discussion

o **Problem Statement (DoD Acquisition Dir & Instr 5000.1 and 5000.2)** - these were revised in 1989 and 1991 to require DoD to determine, disclose, investigate, mitigate and incorporate considerations to not make hazardous effluents during all phases of a weapon system's life cycle, including development. The problem will be to comply with them for the Wingship itself. This is a gross change from the past of simply cleaning up the waste from stationary facilities. The recent revisions were done to include all phases in a weapon system's acquisition life cycle, from phase 0 on through production and deployment. It includes RDT&E, testing, manufacturing, training and deployment. These two regs are the muscles that will require DoD to investigate any unwanted hazardous effluent from a WIG R&D program, even if the projection of effluent is many years and phases away from the present effort DARPA is interested in. The lead agency has a responsibility to DoD to clarify such issues.

o **Noise** - the noise from making "just" 200,000 lb of thrust (4 JT9D engines on a B747) is substantial, possibly at about 106 pNdB. The USN is now having no small amount of difficulty with jet noise at training bases for VF and VA and actually has to run noise surveys and signature predictions before they can get local (meaning town, county and state) approval for F18 squadrons to maneuver off the beach at Oxnard and Port Hueneme. One Oxnard issue was how close can the F-18's get to the beach before they can no longer do a high power turn. The noise criteria maybe two fold - both a not to exceed value and an "average" value which is taken over a 24 hour period. The crux of the problem is that the local community (not the Feds) will always govern in such cases. Oxnard's requirement is to not exceed 55 pNdB - when the surf is 65 (welcome noise that raises the rents) and just

crickets at night in the desert are about 50. The DoD will have to determine where they might like to base a big WIG vehicle, find out what the local laws are and then go about trying to find out what it will take to meet them.

With 10 or more engines, fan and exhaust noise will be something to deal with, both in terms of being a good neighbor during training exercises (see below) as well as a detectable footprint for something that is otherwise as "over the horizon" for radar detection as a cruise missile. At takeoff, the pNdB of a 10,000,000 lb WIG might be like ten B747's taking off simultaneously. It might be hard to hide anything with that big a sound footprint - unless R&D can develop low noise technology for the fans, burners, structures and exhausts of very large engines.

To provide some idea of how much noise a number of engines of identical design would make, the following table was created, and is based upon engines that run the range from quiet to noisy. *[**NOTE ADDED ON 9/20/93** - PWA indicates that their 4084 engine is a geared fan which may be substantially quieter than today's engines. Although the absolute level is not known to the writer, reports to Congress from some of the civil agencies suggest that manufacturers of geared fans are hopefull of getting a 6 dB reduction over current engines - and possibly 10 dB for the aircraft as a whole.]*

Number of Engines	Quiet pNdB	Noisy pNdB
1	106	120
2	109	123
4	112	126
8	115	129
16	118	132
32	121	135

As a point of reference, OSHA standards for noise state that a worker cannot be subjected for more than 8 hours at 90 pNdB, 2 hours at 100 pNdB, 1/2 hr at 110 pNdB or 15 minutes at 115 pNdB. The threshold of pain seems to be around 120 dB.

The above suggests that one of the trades will be to determine if anything can be gained by the use of larger but lesser numbers of engines. The ability to assess engine component noise as a function of sizing factors - airflow, tip speeds, blade passing frequencies, combustor type and nozzle/free stream mixing parameters will be a critical feature in this assessment.

As far as a wet or augmented fan stream version is concerned, the fact that the fan stream is augmented and not

the core will provide noise reductions of up to 7 dB as compared to first mixing the flow and then burning it.

Think ahead to the noise of a 10,000,000 lb WIG landing and taking off with 2,500,000 lbs of thrust. With a 1/3 payload fraction, this would also mean discharging 13,200 men at 250 lbs apiece, or their equivalent, on some local beach. Municipality and beach noise from both engines and cargo is something to be looked at, even now is not too early. For eventual commercial interests in a WIG, noise abatement is an absolute must.

The first step to comply with noise aspects related to 5000.1 and 5000.2 would be to: (1) identify probable noise levels from Wingship engines, given current technology levels. The design values to be played as parameters would be the type, size and number of engines.
(2) Associated with this should also be a study to define local community noise requirements around several possible locations for WIG T&E and training commands, including USMC ocean/beach locations and commercial ports.
(3) Such a study would also be asked to perform a parallel effort which could identify technology solutions to the big WIG noise problem.
(4) Data from the overall study could be used to feed a LO effort with emphasis upon detectability as a prelude to vulnerability.

o Dioxin production from salt water ingestion*[1,2] - Dioxin is not a desirable chemical to release freely as it is a carcinogen with effects (internal organ cancers of all sorts) not showing up usually for years later after exposure. It is frequently associated with the manufacture of Agent Orange during the Vietnam War and was an unsought by-product of the process to make this defoliant. Dioxin can be made during oxidation processes (combustion) if conditions are right. According to the EPA and DOC in Gaithersburg MD, to make it takes the presence of chlorine (as in PVC pipe debris or salt water), an incomplete combustion process (like a municipal dump fire or possibly the period of 30-60 seconds of very rich and incomplete burning in a very wet engine combustor during a start) and temps of 600 to 700 deg C (1112 to 1292 deg F.) - easy to obtain in a dump fire and may be likely on the bottom and side walls of wet combustors once they become soaked throughout with sea water and begin drying out. Till dry, somewhere in the wet system, these temps all exist. If formed, it might be a real threat to the long term health of anyone around these vehicles when started - meaning crew or passengers, all 13,200 of them (for a 10,000,000 lb WIG with 30% payload, all of which are passengers at 225 lbs each.)

The first step to comply with any carcinogenic effluent emissions as perceived by 5000.1 or 5000.2 would be to determine if harmful species of dioxin are or are not formed, ie should the Wingship have something to worry about or not?? ***The Russians commented that they felt the US was obliged to get answers on this topic.***

(1) Run some laboratory combustion tests with salt water sprayed and puddled on and inside the liners and cases to see if a harmful species of dioxin could be produced. A review of relevant combustion work would also be appropriate via the literature and known experts in this field.

(2) Get sufficient T&E in the lab to identify species, life spans of species and some feel for what it would be likely to do to humans. Try to identify/devise possible mechanisms for transfer to the human environment. Try to develop some relatively simple techniques to avoid or somehow mitigate any dioxin formations.

(3) Develop fieldable measuring equipment and check out their suitability by going to the operational Navy including carriers at sea to find out if Dioxins are being made.

(4) Do some engine testing under WIG "flying" and at rest conditions in both light and heavy sea states to see if engines can have a dioxin problem under WIG conditions of either storage or use.

If there is a problem, the second step would be to work out some ways in the lab to make it go away and then do full scale engine tests to verify that the techniques are effective.

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*1 **Is** dioxin formed by gas turbines ingesting salt water?? This does not seem to be a problem for crews on carrier decks working in and around nacelles. However, when a lot of salt water has been ingested in a dormant engine, this may be a different matter, as follows. The NAVAIR specs for engine salt water ingestion testing during development and prior to production release require a continuous misting spray in the inlet and on the outer case for hours before initiating a start and doing some regular operational testing for power and accelerations. This is felt by the author to be substantially more water both externally and inside the engine than is normally experienced by an engine installed in an aircraft and parked on the flight deck in rough seas. However, it may have a closer correspondence to the amount of liquid sea water an engine mounted on a Wingship might get "sloshed" into it while at anchor or sea sitting. In the mid 1970's, four men in the age bracket of 35 to 45 at NAPC Trenton (now NAWC/AD) died of cancers, all over a 3 to 5 year period. Each had come to Trenton from the Phila Naval Yard where they had participated as engineers and crew in a salt water ingestion test of a turboprop engine in the 1960's. This was the only test found in their careers that they all had in common. Two other crew members still survive that test, one being the chief civilian at NAPC in 1993. The deaths of the four and the potential for a tie-in with the prior salt water ingestion test has been discussed with Trenton at the head civilian level, and lower, as well as

with the civilian head of NAVAIR's Propulsion Division, AIR 536, with no apparent effect. Neither Trenton nor NAVAIR has ever done any visible T&E work to establish whether or not this type of testing produces a hazardous effluent. It is said by their head civilian to not be mentioned in their EIS.

*2 When the subject of dioxin as a possible JP fuel/salt water combustion by-product was raised in Wingsip Committee meetings, the group expressed some concern for the by-products of combustion with the other chemicals that are present as dissolved solids in sea water (about 5 major ones), not just NaCl. Consequently, it is suggested that if studies are ever triggered by the above information, that they address all the major materials found in salt water. See the section in Appendix N on water washing of engines which identifies the contents of salt water, as a specification, since salt water varies substantially in dissolved solids worldwide.

As we know, while operating gas-turbine engines in marine environment we face a number of problems:

- agressive influence of marine environment on the structure of the engine
- accumulation of salt in the duct which leads to the increase of temperature of gases and reduces the stability reserve.

Additional problems concerning the operation of GTE on wingships are:

- the flight in ground effect causes penetration of salty aerosol into the engine. Also, on the wingship it is practically impossible to achieve complete separation of water on the intake
- overloads on the engine due to vibrations during take-off and landing which could cause damage to an aircraft engine
- while converting an aircraft GTE for water-displacement ships, to increase the reserve on operating ability it is necessary to reduce the temperature of the take-off mode by 100–150 °C.

Thus, while creating the marine engine (GTE) LM-2500 on the basis of the aircraft GTE TF-39 General Electric had to reduce the gas temperature of the maximum mode by 160°.

While converting aircraft GTE for the wingships, which require considerable thrust efforts, it is not considered reasonable to use throttling of modes.

All these peculiarities determine the methods of creating and ~~adapt~~ adjusting converted engines for the wingships. Here are the most important ones of these methods:

- using ~~eng~~ GTE of two types - ~~booster~~ starting and midflight

Since midflight engines must be highly efficient, they should be created on the basis of modern aircraft engines.

~~booster~~ engines, since they are used only for a short period of time, do not affect the efficiency of the wingship in general. So these are the main requirements in them:

- sufficient power
- operational reliability
- temperature reserve for the presence of salt
- considerable backup on small-cycle fatigue

Technico-economical analysis showed that the best starting ~~booster~~ engine for a wingship will be an aircraft engine with moderate parameters.

For example - GTE NK-87 converted from the aircraft engine NK-86 designed by the firm of Chief Designer N.D. Kuznetsov.

Its t_{gas} equal to 1260 K, the engine still operates when t_{gas} increases by 50-60 C because of the presence of salt.

The engine has a considerable backup on small-cycle fatigue, and if used as a starting ~~booster~~ power plant, one set of engine will last during the entire ~~whole~~ service life of the wingship.

A whole complex of research has been conducted on the engine, according to the requirements with due imitation of operation conditions.

In order to detect flaws caused by unstable factors of engine operation the engines are supplied with a parametric diagnostic system connected with the on-board computer, and also a series of optical boroscopes, whirling vortex-current and ultrasonic equipment and manipulators of delivering measuring detector devices to the inner cavities of the engine. For examining the engine they also use a remote-control optical system with a small TV camera.

For a midflight engine of a wingship, the Kuznetsov firm has come up with a marine modification of a turboprop engine NK-12MA ("Orlan" wingship) They also are trying to optimize it (engine NK-26)

At present they are working on a unducted fan propofan engine NK-93:

take-off thrust – 1800 kg

fuel consumption specific – $0.2 \frac{kg}{kg_{thrust} \cdot hr}$ $(H=0, M=0)$

fuel consumption specific – $0.35 \frac{kg}{kg_{thrust} \cdot hr}$ $(H=0, M=0.35)$

Also they have worked out the layout for the engine NK-44

take-off thrust – 40000 kgs

fuel consumption specific – $H=0, M=0$ $0.327 \frac{kg}{kg_{thrust} \cdot hr}$

fuel consumption specific – $H=0, M=0.35$ → $0.47 \frac{kg}{kg_{thrust} \cdot hr}$

The most rational method of converting is parallel of the basic and the converted engine, as it was done, for example, by General Electric when they were building marine LM-2500. Parallel enables the designer to incorporate serious adjustments on providing availability of a GTE in marine environment without breaking an established technological process.

The problem of ~~specif~~ certification occupies an important position in the process of and testing of converted engines.

Most probably these engines will still fall under the aviation norms and requirements. Peculiar operating conditions of aircraft GTE in the marine environment will call for introducing some corrections into the requirements of FAR and the corresponding Russian structure

Leading Designer Mr. Perevozkin

All my loving to my friend "the Chief"!

Elena Kapoustona